THE HYDROGEOLOGY OF THE KAIKOURA PLAINS, NORTH CANTERBURY, NEW ZEALAND.

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Frontispiece: Kaikoura Groundwater.

ABSTRACT

In the last decade the Kaikoura Plains have undergone an intensification of dairy farming, and are also currently undergoing an increase in transient population due to a booming tourism industry. This increase in both farming and population have potential in the future to overexploit the Kaikoura groundwater system. The purpose of this study therefore, was to assess the groundwater system of the Kaikoura Plains to facilitate long term management of the groundwater resource.

Hydrogeological and geophysical investigations, combined with baseline data collection, have provided the basis for the development of a conceptual hydrogeological and water balance model of the Kaikoura groundwater system. Geological mapping of the surficial Quaternary alluvial deposits was undertaken, as was the interpretation and correlation of borehole lithologic logs and two transient electromagnetic surveys. These investigations have confirmed the presence of three aquifers, Aquifer 1 which is unconfined, Aquifer 2 which semi-confined to confined, and Aquifer 3 which is confined. Of these three aquifers only Aquifers 1 and 2 are currently utilized. A substantial thickness of unexplored alluvial deposits was also identified, beyond the depths of current wells.

A water balance was calculated for the Kaikoura groundwater system from a very limited database, and as such is subject to a degree of uncertainty. The main inputs and outputs identified for the Kaikoura groundwater system were: recharge from rainfall infiltration; the subsurface leakage of surface flow from the Kowhai River and the streams draining the seaward slopes of Mt. Fyffe; discharge via springs and areas of seepage to streams and drains on the lower surfaces of the Kaikoura Plains; and discharge via offshore springs at the sea bed. Recharge via rainfall infiltration is the main source of groundwater recharge at 1775 l/s, followed by recharge via leakage from the Kowhai River, ranging from 480 l/s to 830 l/s under summer and winter conditions respectively, and recharge from leakage from the streams draining the seaward slopes of Mt. Fyffe, ranging from 180 l/s to 440 l/s. Discharge from

seepage to springs and drains ranges from 810 l/s to 1160 l/s while offshore discharge has been estimated from 1635 l/s to 1865 l/s.

Chemical analyses of water samples from Aquifers 1 and 2 displayed very similar characteristics and could not be used for differentiation between the aquifers. Piper diagrams of the major ion data show almost identical plot positions for both Aquifer 1 and Aquifer 2,and both aquifers displayed the same evolutionary trends. Comparison of analyses from two separate sampling occasions indicate that microbiological contamination of groundwater is extremely variable and that the unconfined aquifers are the most susceptible to microbiological contamination.

The main conclusions drawn from this study are that:

1. The Kaikoura groundwater system consists of one unconfined aquifer (Aquifer1) and two confined aquifers (Aquifers 2 and 3), with only the unconfined and upper confined aquifers being utilized.

2. The water balance of the Kaikoura groundwater system is in a state of equilibrium under both winter and summer conditions, indicating that a substantial groundwater resource is available for exploitation.

3. The water balance for the Kaikoura groundwater system presented in this study provides a basis for numerical modelling and future management of the groundwater resource of the Kaikoura Plains.

4. Further work is required in baseline monitoring of the Kaikoura groundwater system in order to expand the current database to allow more quantitative and definitive conclusions to be drawn. The drilling of a deep borehole is also required to prove the groundwater resource indicated by geophysical surveys.

ACKNOWLEDGMENTS

I gratefully acknowledge the Canterbury Regional Council and staff for providing the funding and support for this project, in particular the efforts of Michael Dicker who made the project possible. I am also grateful to my co-supervisors; David Bell for introducing me to the project and keeping me on track, and Dr. David Nobes for his geophysical advice and conducting the geophysical surveys.

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1. INTRODUCTION

1.1. BACKGROUND

The Kaikoura Plains are located on the East Coast of the South Island of New Zealand, approximately 150km northeast of Christchurch (Figure 1.1). The Kaikoura area has a growing farming and tourism industry, and also a corresponding growth in population especially during the summer months. This increase in both population and farming places increasing demands on the present public water supply system, an infiltration gallery in the bed of the Waimangarara River, which is subject to problems of both water supply and water quality. When river conditions are such that water from the infiltration gallery becomes turbid the water supply is switched to a groundwater bore which is unable to keep pace with the demand for water. The present project was therefore funded by the Canterbury Regional Council in order to assess the regional groundwater system in terms identifying the aquifers present beneath the Kaikoura Plains, determining aquifer characteristics and developing a conceptual hydrogeological water balance model for the Kaikoura aquifer system.

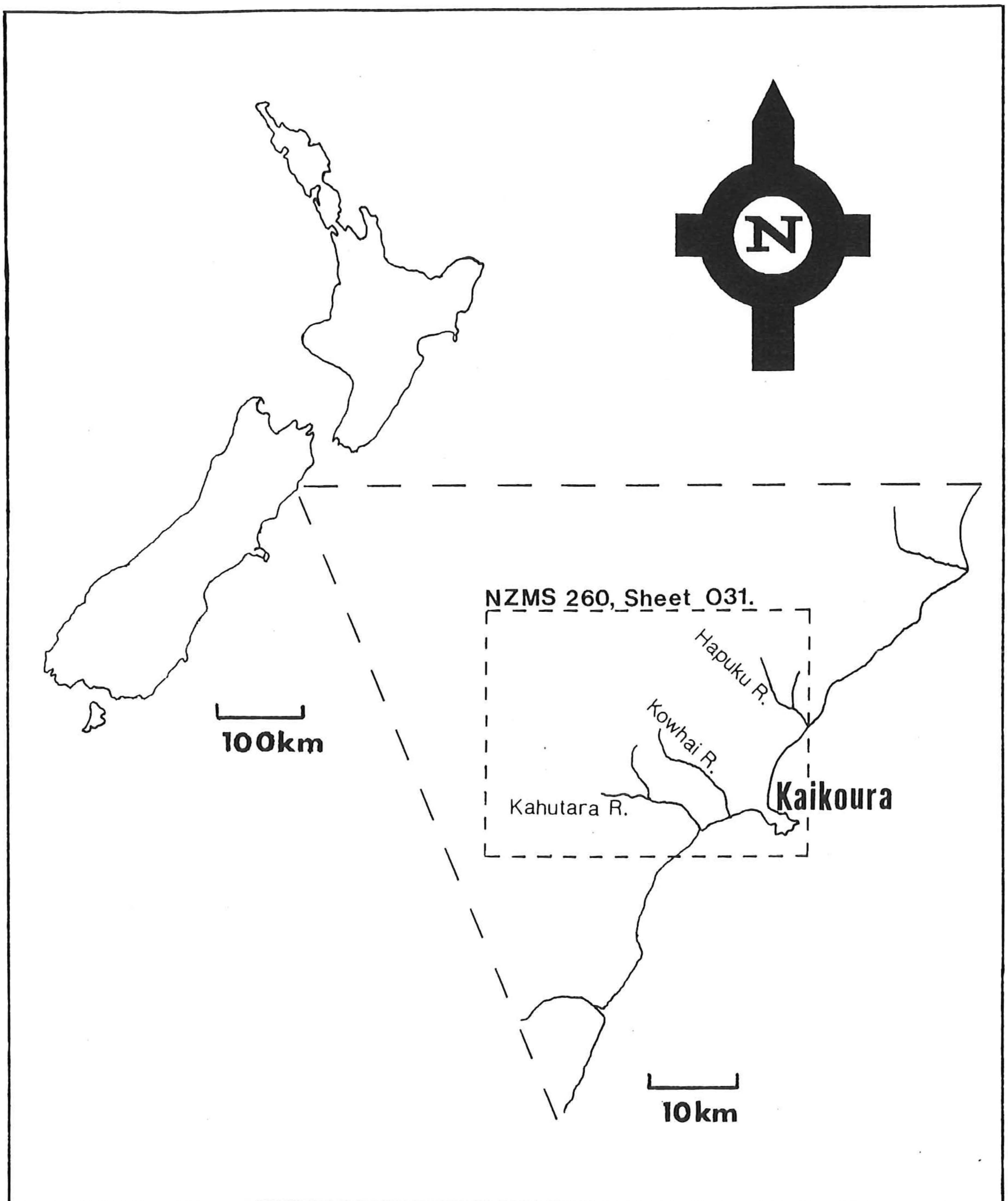
1.2. OBJECTIVES

The project objective is to complete a detailed hydrogeological investigation of the Kaikoura Plains and develop a conceptual hydrogeological model to facilitate the emplacement of a long term groundwater management plan.

This primary objective consists of four discrete stages, each with its own specific requirements. These are as follows:

1. to determine depth to basement and internal structure within the alluvial cover deposits using geological and geophysical techniques, with the specific aim of identifying the aquifer system present beneath the Kaikoura Plains,

2. to identify and evaluate aquifer recharge zones and to determine any relationship between surface flow (particularly in the Kowhai River) and groundwater levels and flows,



KAIKOURA LOCALITY MAP

FIGURE 1.1.

3. variability, to identify any point sources of existing or potential contamination, and to evaluate the likelihood of any saltwater incursion along the coast,

4. to delineate aquifer boundaries, to characterise aquifer properties, to develop a conceptual geological model, and to determine a water balance for the Kaikoura Plains aquifer system.

1.3. PREVIOUS WORK

The Kaikoura area has been the subject of numerous geological and geomorphological studies and investigations; the majority of the studies have been concerned with the areas tectonic and deformation history and its past and present coastal processes. However, a number of studies have been concerned in part, if not in full, with the geology and hydrogeology of the Kaikoura Plains. Chandra (1968, 1969) studied the geomorphology of the Kaikoura area, identifying the major physiographic units of the area and the processes and chronological sequence of events which have given rise to the landforms present today. Brown and Taylor (1974) combined geological, hydrological and isotopic evidence to aid in the interpretation of the groundwater hydrology and post-glacial geology of the Kaikoura Plain. Their investigations represented an attempt to assess the effect on Kaikoura's groundwater resource of a drainage scheme proposed by the then Marlborough Catchment Board. Brown (1988) discussed Quaternary geology and geohydrology and presents data from wells, for the area between the Conway and Clarence Rivers including the Kaikoura Plains. Brown utilised information presented by Brown and Taylor (1974) along with new data to aid with planning and management options for the groundwater resource. One of the most recent works on the Kaikoura area is that by Van Dissen and Brown (1995) which discusses late Quaternary geology and faulting in the Kaikoura region with a view to determining rates of uplift and strike-slip movement, and earthquake recurrence intervals along the various segments of the Hope Fault, the Jordan Thrust, and the Kekerengu, Fidget, Fyffe and Kowhai faults. Van Dissen and Brown (1995) also present a revised version of Brown's (1988) geological map of the Kaikoura area. Numerous other smaller papers and reports have been prepared on topics such as water quality and geophysical surveys; these will be referred to in later sections where appropriate.

1.4. PHYSIOGRAPHIC SETTING

The Kaikoura Plains as defined for this study occur over an area of approximately 100 km^2 and are bounded to the northeast by the Hapuku River; to southwest by the Kahutara Hills; to the north by Mount Fyffe and the Seaward Kaikoura Range and to the south and east by the Pacific Ocean and the Kaikoura Peninsula (Figures 1.2 and 1.3).

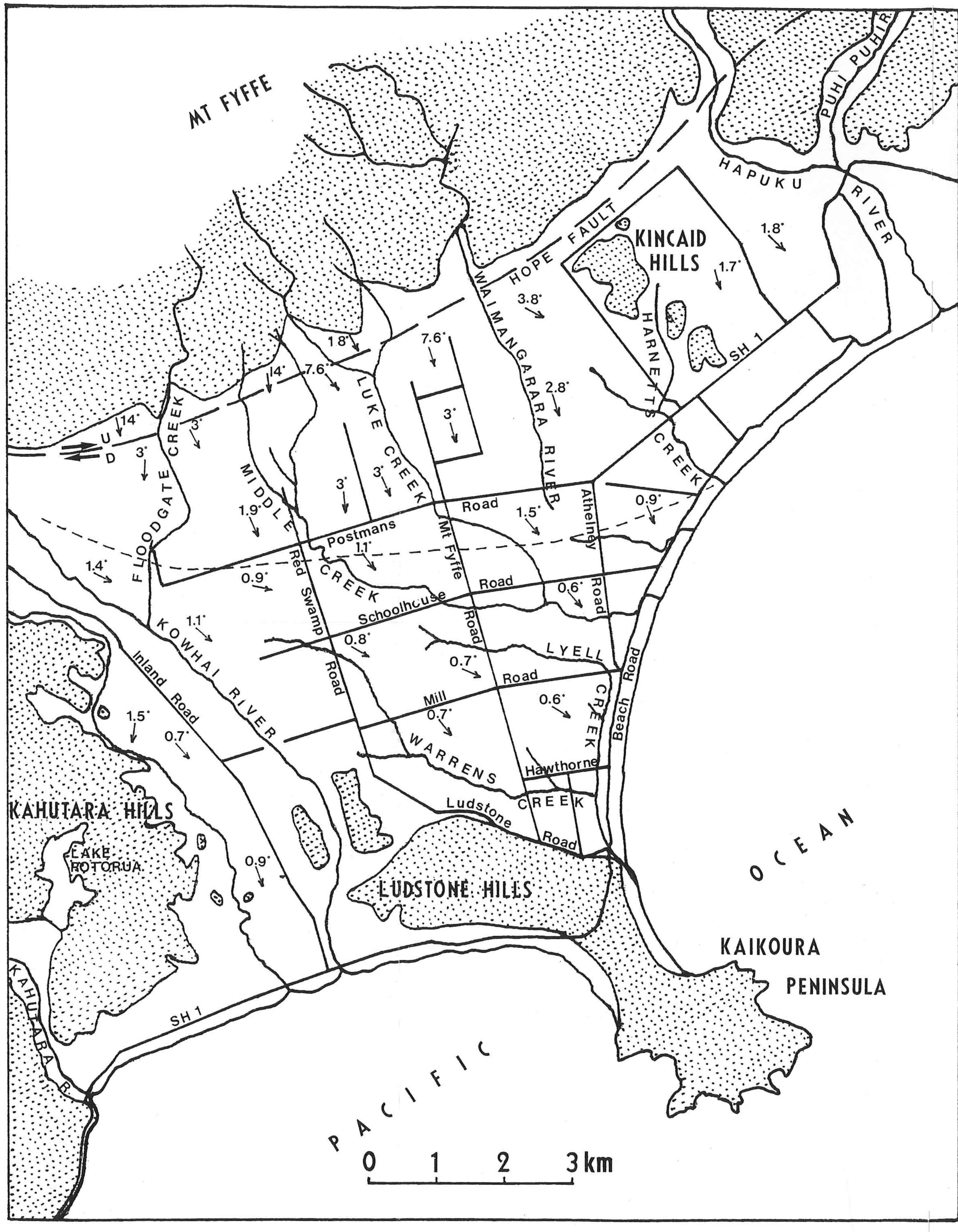
A prominent characteristic of the Kaikoura Plains is the steep gradient. The slope of the plains along Mt. Fyffe Road changes at around about the fifty metre contour, this break in slope marks the extent of deposition of coarse grained fan sediments by the Mt. Fyffe streams. Above the break in slope the seawards gradient of the plains is, on average, about 45m/km (2.8°) and below is about 14m/km (0.8°). The Kaikoura Plains consist of relatively flat land with some low, rolling hills. These low hills are inliers of Tertiary and Cretaceous age rock surrounded by Quaternary age alluvial and swamp deposits. It is within these Quaternary deposits, formed by the coalescing fans of the Kowhai and Hapuku Rivers and the Mount Fyffe streams, that the most significant groundwater resource of the Kaikoura Plains is to be found.

The Kaikoura Plains are dissected by a large number of artificial and natural water courses. These water courses are principally fed by springs, seepages and runoff from the lower plains surface. The Kowhai and Hapuku Rivers receive runoff from the inland slopes of Mt. Fyffe and the Seaward Kaikoura Mountains. Harnetts Creek, the Waimangarara River, Luke Creek, Middle Creek and Floodgate Creek all drain the seaward slopes of Mt. Fyffe, while the lower reaches of Middle Creek, Warrens Creek and Lyell Creek drain the Kaikoura Plains themselves. The Waimangarara River and Luke and Floodgate Creeks, and the upper reaches of Middle Creek however, all lose their flows completely into their fans after flowing only a short distance onto the Kaikoura Plains. The presence of drainage ditches on the Plains, constructed at various stages since the late 1800's, usually coincides with areas of impeded drainage, generally silt and clay of flood and swamp deposits.

After extended periods of wet weather, water seepages appear over a large proportion of the plains as the elevated water table intersects with the Plains surface, and there are several springs and seepage areas which flow year round.

Figure 1.2. Oblique aerial view of the Kaikoura Plains.

Photo: Dr. D. C. Nobes, Dept. of Geological Sciences, University of Canterbury.



Physiography of the Kaikoura Plains.

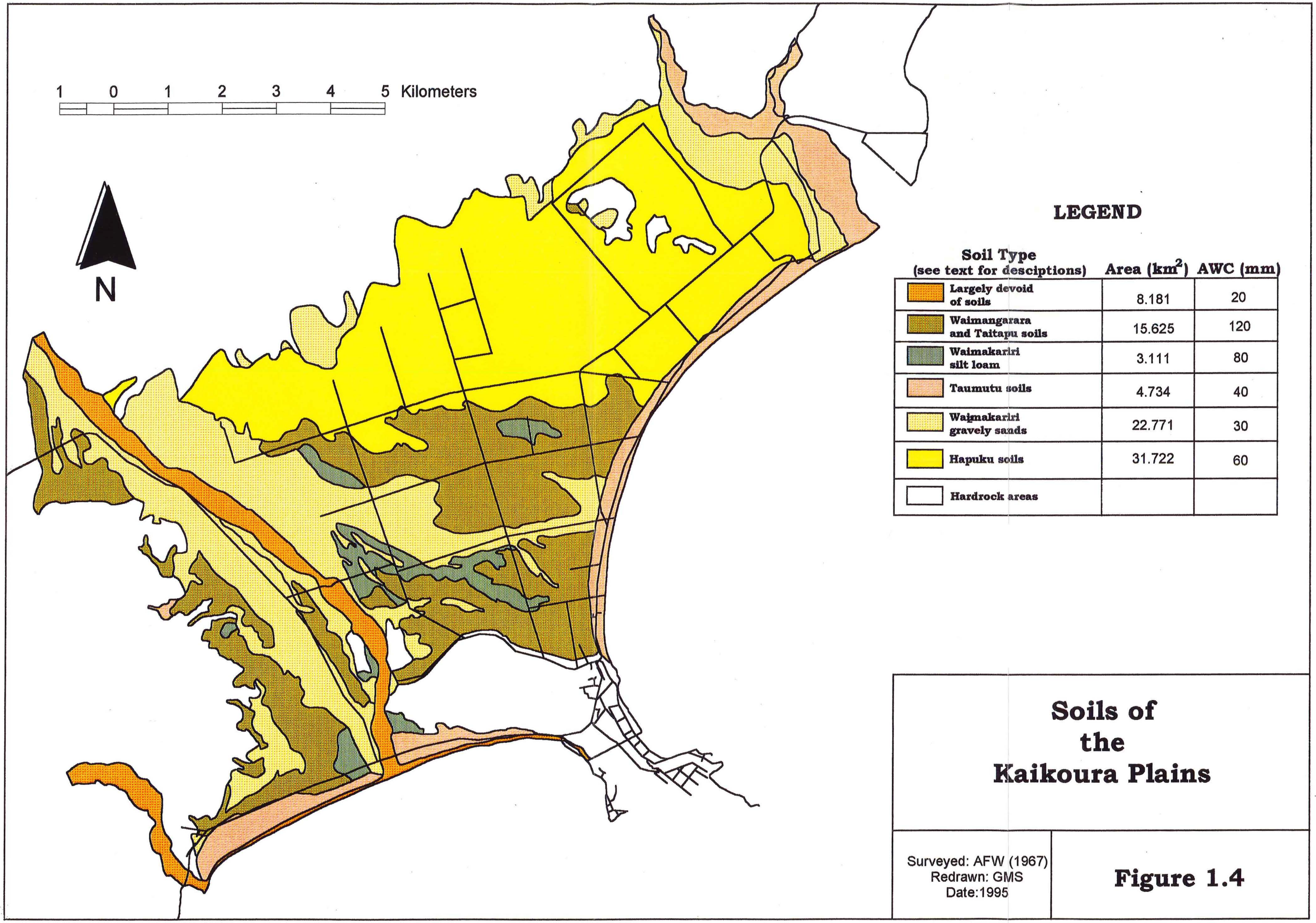
Figure 1.3

1.5. Soils

The soils of the Kaikoura Plains were mapped by the Marlborough Catchment Board (Thomson and Macarthur, 1969) as a part of the "Kaikoura Scheme" to improve drainage and flood protection works on the Plains. A modified version of this map is given in Figure 1.4. Nomenclature of soils is outlined in Appendix I and is taken from the D.S.I.R. Soil Bureau Bulletin No. 25 (Taylor and Pohlen, 1979). The soils of the Kaikoura Plains can be broadly divided into those formed on the relatively free-draining alluvial fans of the Kowhai and Hapuku Rivers and the Mt. Fyffe streams, and those formed on the low lying areas with a permanently high water table and impeded drainage. Table 1.1. outlines the soils present on the Kaikoura Plains.

Hapuku Loams.	These consist of a series of closely related soils covering approximately 2230 ha (22.3km2) on the upper Plains area. The soils are of variable grainsize, free draining, and are derived from older fan material from the Hapuku River and the Mt. Fyffe streams.
Waimakariri gravely sand.	A fairly extensive area of soils derived from stony or sandy alluvial deposits on both sides of the Kowhai River floodplain. These soils are free draining, of low moisture holding capacity and low or moderate fertility.
Waimakariri silt loam.	This soil is associated with Waimakariri gravely sands but is deeper and has a finer texture, resulting in a greater moisture holding capacity than the gravely sand. Limited to about 405ha (4.05km2).
Waimangarara silt loam.	An extensive soil type formed on the lower Plains from fine textured alluvium (flood silts). High natural fertility. Areas suffering from impeded drainage exhibit a characteristic gray mottling. High moisture holding capacity.
Taitapu heavy silt loam.	This soil type is of high fertility and high moisture holding capacity and is only present in localised areas south of the Kowhai River.
Taumutu stony gravels.	These are free draining stony sandy soils formed along the coastal margins of the Kaikoura Plains on the raised beach ridges both north and south of Kaikoura. Fertility is moderate to low and soil moisture holding capacity is low.

Table 1.1. Soils of the Kaikoura Plains.



Soil Type (see text for desciptions)	Area (km²)	AWC (mm)
Largely devoid of soils	8.181	20
Waimangarara and Taitapu soils	15.625	120
Waimakariri silt loam	3.111	80
Taumutu soils	4.734	40
Waimakariri gravely sands	22.771	30
Hapuku soils	31.722	60
Hardrock areas		

Soils of the Kaikoura Plains

Surveyed: AFW (1967)
Redrawn: GMS
Date:1995

Figure 1.4

Available soil water capacity (AWC) for the soils has been estimated (Appendix I) and is illustrated in Figure 1.4. The available soil water capacity can be used as a measure of how much rainfall is likely to enter the groundwater system via direct infiltration. Once a soil has become saturated its available soil water capacity has been met. After this point any extra water will be lost to either surface flow, evaporation or to groundwater. AWC is inversely proportional to the permeability and average grain size of a soil, thus for the soils of the low lying areas of the Kaikoura Plains which exhibit high AWC values and low permeability the amount of excess water lost to groundwater will be negligible. Conversely for the free draining fan soils with low AWC values the amount of excess water lost to groundwater is likely to be quite high.

1.6. Climate

The Kaikoura Plains are often subject to their own localised microclimate. The close proximity of the sea has resulted in Kaikoura having a reasonably mild climate, with temperatures reaching the 30°c during summer and occasionally freezing during winter.

Rain falls on average about 130 days per year and averages from 825mm on the Peninsula to 1375mm at the base of Mt. Fyffe. and even more on the upper slopes of Mt. Fyffe. The plains receive a lot of rainfall from easterly directions as the close proximity of Mt. Fyffe and the Seaward Kaikoura Ranges forces moisture laden clouds coming from the sea to rain heavily in order to be able to gain sufficient elevation to pass over the ranges. A lot of rain is also received from both southerly and northwesterly fronts advancing over the country. Table 1.2. shows average monthly rainfall at the base of Mt. Fyffe.

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
127	153	197	158	140	145	164	132	143	153	144	141

Table 1.2. Average monthly rainfall (mm) on the Kaikoura Plains.

Snow may fall on Mt. Fyffe at any time of the year, usually from the passing southerly fronts; Mt. Fyffe and the Seaward Kaikoura Ranges are usually covered in snow down to about 2500m for 4-6 months of the year. High stream and river flows often result when snow from the south is followed by rain from the northwest.

Although there is no data available on rates of evaporation it is considerably less than on the Canterbury Plains due to the lack of the hot dry northwesterly winds which predominate Canterbury Plains summers.

1.7. Landuse

The Kaikoura Plains. Dairy farming is the dominant form of agricultural in Kaikoura while beef, sheep, deer and pig farming and horse breeding are present, they have not developed, commercially , to the same extent as the dairy industry. Horticulture on the Kaikoura Plains consists of two nurseries, an orchard and a market garden.

Over the last decade the Kaikoura area has seen intensification of dairy farming that has placed increasing demands on existing groundwater supplies, especially over the summer months when irrigation is required to keep milk production at acceptable levels. Farming in the area, especially dairy and pig farming, has in the past posed a threat to the quality of shallow groundwater resulting primarily from unsound methods for disposal of effluent. Until recently it has been common practice to discharge undiluted effluent directly into waterways, thus creating unnecessary sources of contamination, particularly microbial and nitrate contamination. On the basis of guidelines set out by the Canterbury Regional Council, however, effluent disposal practices are improving with a number of farms using spray irrigators to dispose of effluent. By spraying diluted effluent over a large area the risk of groundwater contamination is minimised.

The Kaikoura area is also currently in the midst of a tourism boom with the large numbers of visitors currently passing through Kaikoura expected to increase. This growth in tourism is due to the exploitation of Kaikoura's abundant wildlife and the rugged beauty of its coastlines and mountains. Of particular interest to visitors is the chance to observe whales in their natural environment, the presence of the edge of the continental shelf and the Hikurangi Trench only kilometers offshore means that the water is deep enough for the whales to dive and feed only a short boat ride from Kaikoura. The increase in population will put increasing demands on the district water supply, and the District Council is looking for another groundwater supply to supplement its existing surface water infiltration gallery near the gorge of the Waimangarara River, and replace the existing, substandard groundwater supply.

1.8. Investigation Procedure

To enable the objectives outlined earlier (section 1.2) to be realised, the following tasks were undertaken:

1. a review of the existing database on groundwater resources of the Kaikoura Plain,

2. identification of existing wells and associated well logs, pump test data and depths of abstraction,

3. groundwater sampling and analysis to identify any aquifer-specific chemical patterns and variations in groundwater type and quality,

4. mapping of aquifers and bedrock topography using geophysical techniques and correlations with borehole data and surficial geology,

5. construction of potentiometric contour maps,

6. stream gauging to determine groundwater inputs and outputs,

7. identification of aquifer boundaries and their nature, aquifer extent and aquifer recharge zones,

8. determination of the effects of precipitation and river recharge on groundwater levels and aquifer response times,

9. pump testing of existing wells to obtain values for aquifer hydraulic conductivity, storativity and transmissivity, and

10. construction of a water balance and conceptual hydrogeological model for the Kaikoura Plains area.

1.9. PROJECT SUPPORT

This project was carried out with financial and logistical assistance from the Canterbury Regional Council, for which they are gratefully acknowledged. All research and technical investigations conducted for this project were undertaken by the writer with the help and advice of Canterbury Regional Council staff.

1.10. THESIS FORMAT

This thesis consists of seven chapters each dealing with one more of the tasks outlined in section 1.8. above: Chapter 2 deals is concerned with the geology of the Kaikoura area, the Regional geology is summarised and the writers interpretation of the Quaternary geology is given. Chapter 3 discusses the geophysical aspect of this study. A transient electromagnetic survey was carried out in order to determine depths to base rock, and to attempt to identify any internal structure within the alluvial cover deposits. Chapter 4 investigates the hydrogeological and hydrological aspects of the Kaikoura groundwater system and describes the aquifer system present beneath the Kaikoura Plains. Chapter 5 discusses groundwater chemistry and its implications. Chapter 6 outlines the components of a water balance model and presents a conceptual hydrogeological model for the Kaikoura Plains aquifer system. And finally Chapter 7 summarises the main points of the previous chapters.

2. GEOLOGY

2.1 Introduction

The objective of this section is to outline the geological environment in which the Kaikoura Plains were formed and to describe the processes and events which have given rise to their configuration form. The following sections describe the geology of the Kaikoura Plains in terms of their geological setting, the elements of Quaternary geology which make up the Plains and the sequence of geomorphic evolution which formed them.

2.2 Geological Setting

The regional geology of the Kaikoura area (Figure 2.1) has been largely influenced by its close proximity to the transform fault system of the Indo-Australian and Pacific plate boundary. This convergent plate boundary, represented by the Alpine Fault and the Marlborough fault system, and the associated tectonic uplift of the Kaikoura Orogeny, has influenced and shaped the landscape of the Kaikoura area. One of the main faults of the Marlborough fault system, the Hope Fault, is a steeply dipping reverse fault that runs along the seaward base of Mt. Fyffe (Figure 2.1 & 2.2).

2.2.1 Mapped Lithologies

Brown (1988), after Lensen (1975), classed the geology of the Kaikoura area into four basic groups of rocks based on their age and origin, as follows:

Jurassic to Lower Cretaceous Greywacke and Argillite of the Torlesse Super Group.

> These highly jointed, folded and faulted concretionary sandstones and mudstones form the bulk of the mountain ranges including Mt. Fyffe, the Seaward Kaikoura Range and the Kahutara Hills. These sediments contain rare conglomerates and limestones and were intruded intermittently by basic igneous dykes before being subjected to low grade regional metamorphism.

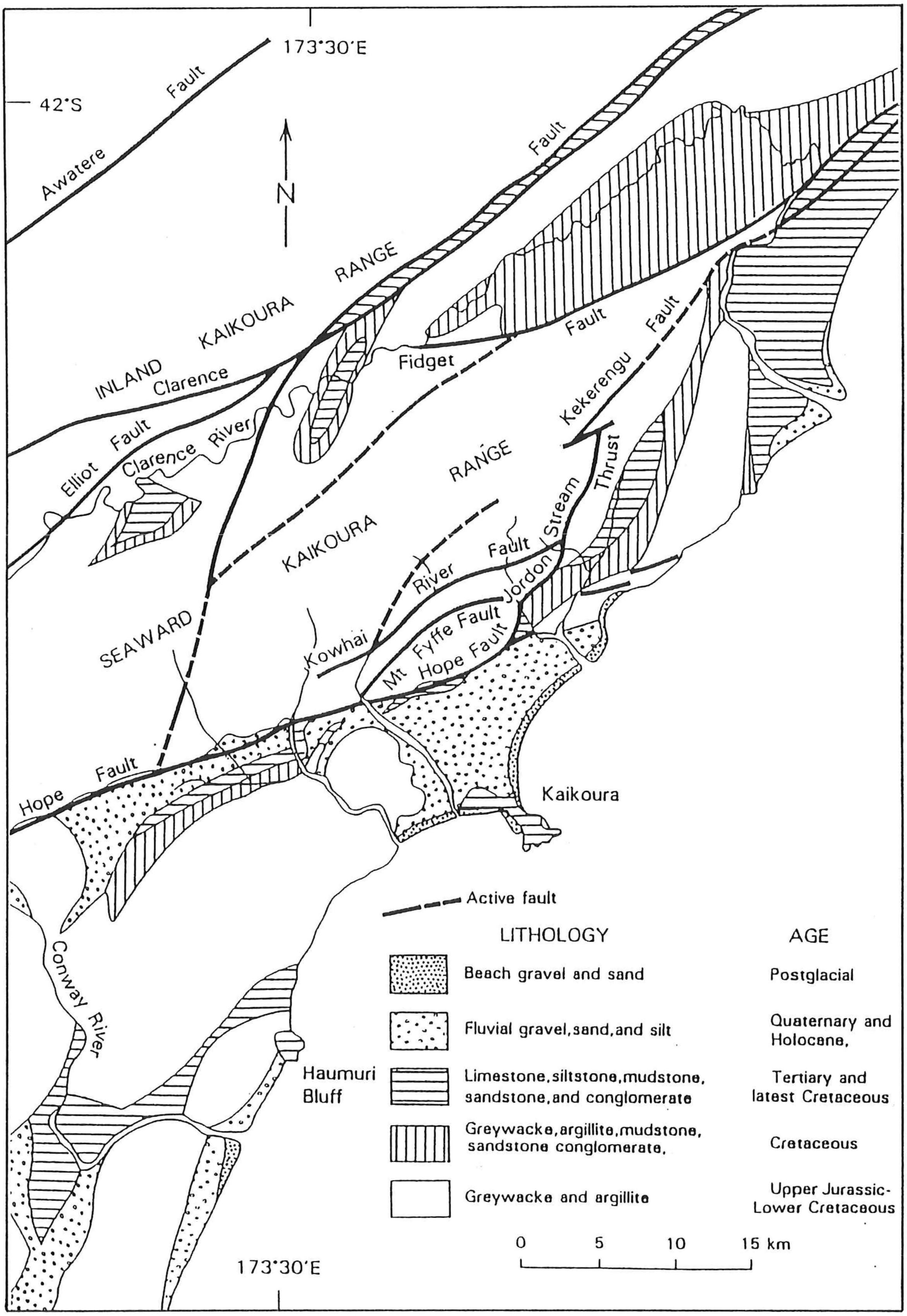


FIGURE 2.1. GEOLOGY OF THE KAIKOURA AREA.

(Source: Brown, 1988)

Mid to Late Cretaceous Sandstones and Mudstones of the Torlesse Super Group.

Interbedded with these massive concretionary sandstones and mudstones are intraformational conglomerate and coal measures which mark changes in the depositional environment from marine to terrestrial and then back to marine deposition. Also interbedded within these sandstones and mudstones are terrestrial and marine basalt flows and volcaniclastic sediments. These lithologies tends to be less resistant to erosion than the Jurassic to Cretaceous age greywacke and argillite, and as such, tend to have less prominent and more eroded features than the older Torlesse lithologies.

Latest Cretaceous to Tertiary Sedimentary Rocks.

These sedimentary rocks consist of limestone, siltstone, mudstone, sandstone, conglomerate and coal measures which form the Pareora-Southland, Landon, Arnold, Dannevirke and Mata Series. These lithologies outcrop on the Kaikoura Peninsula, the Ludstone Hills and the Kincaid Hills.

Quaternary deposits.

Quaternary deposits are preserved on the higher fan surfaces of the Hapuku River and on some surfaces of the fans of the Mt. Fyffe streams. These Quaternary sediments consist of interglacial marine gravels, glacial outwash deposits and post-glacial fluvial and marine sand, silt and gravel. These correlatives of the Parikawa, Burnham and Springston Formations form the bulk of the Kaikoura Plains.

2.2.2 Structure and Tectonics

The Kaikoura area is located near the junction of the Hope Fault and the Jordan Thrust (Figure 2.1). Lateral displacements exceeding 150m during the late Quaternary have been documented along the Kahutara and Mt. Fyffe segments of the Hope fault(Van Dissen and Brown). However, this amount of displacement has not been observed along the Seaward segment of the Hope Fault. Displacement was instead transferred northwards through the Jordan Thrust, with the consequent uplift of the of the Seaward Kaikoura Range (Van Dissen and Brown, 1995).

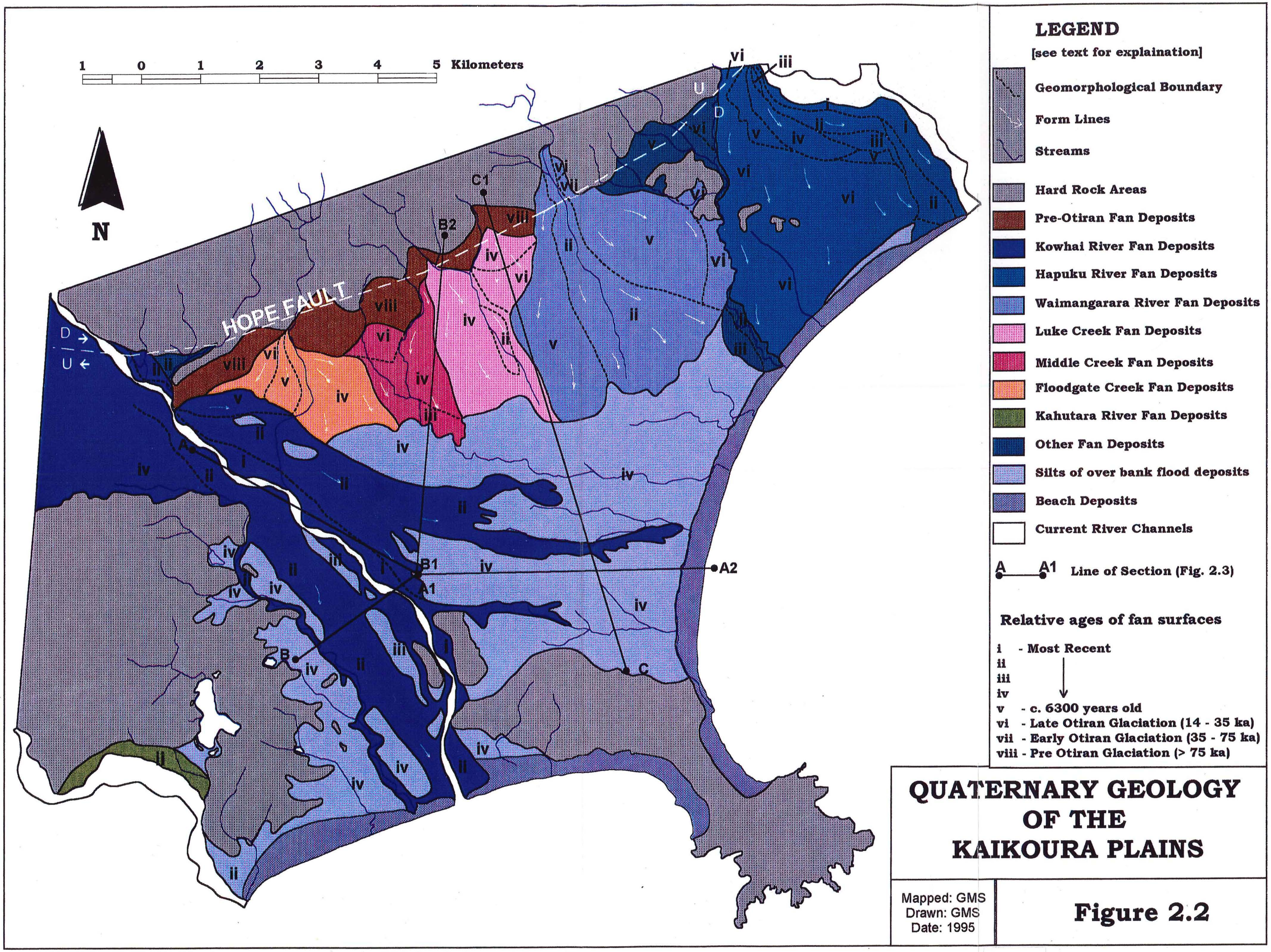
The Hope Fault (Figures 2.1 & 2.2) has been one of the most active of the Marlborough faults during the Quaternary, accommodating at least one half and possibly as much as three quarters of the motion along the Indo-Australian/Pacific plate boundary (Van Dissen and Brown, 1995). In general the Hope Fault is a steeply dipping reverse fault with average dip of about 70° to the northwest, and trending at approximately 070° (Figure 2.3). In the study area the Hope Fault is represented by the Mt. Fyffe segment, which is bounded by the Kowhai River to the east, by the Hapuku River to the west, and it curves around the base of Mt. Fyffe (Figure 2.2). The western portion of the fault segment trends at about 080° and has a predominantly right-lateral strike-slip displacement with a minor vertical component, up to the south. The eastern portion of the fault segment trends at about 060° and has a predominantly reverse displacement, up to the northwest, and a lesser right-lateral strike-slip component. This difference in sense of movement along the fault is due to the curving nature of the fault segment, forming a constraining bend and hence a transpressional tectonic environment to the east and releasing bend with a transtensional tectonic environment to the west. Near the middle of the fault segment, between Middle Creek and Luke Creek, the fault plane dips at 70° to the northwest (Figure 2.3).

The presence of the Hope Fault along the landwards margin of the Kaikoura Plains, and the close proximity of other active faults such as the Mt. Fyffe Fault, the Kowhai River Fault and the Jordan Thrust (Figure 2.1), has provided an enormous source of fractured, and easily erodable material for the building of the Kaikoura Plains.

2.3 Quaternary Geology

2.3.1 General

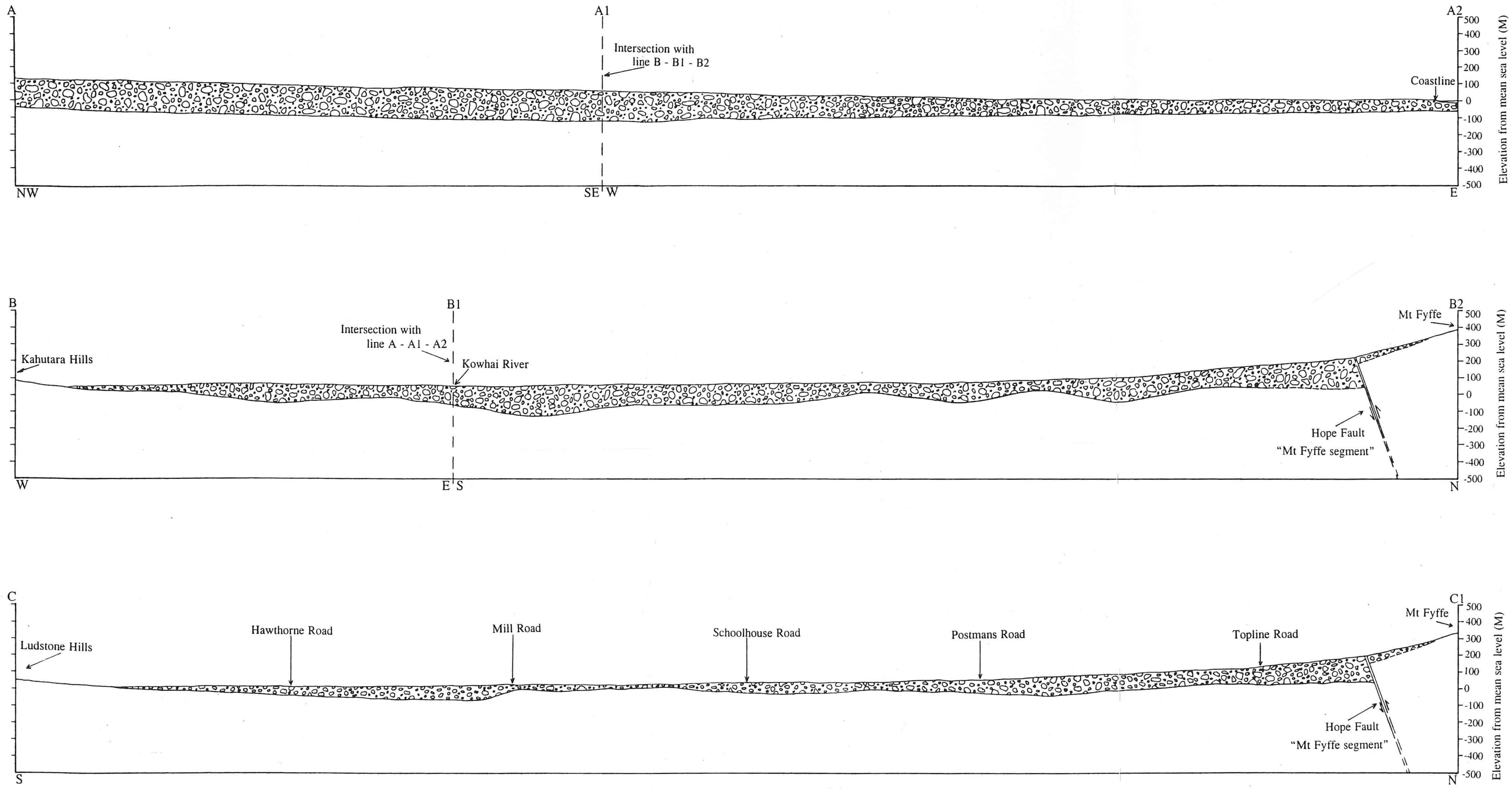
During the last two million years, fluctuations in the world's climate have resulted in numerous alternating glacial and interglacial periods. These alternating periods each had characteristic depositional trends. During the glacial periods deposition was largely dominated by fluvio-glacial gravel and sand, while the interglacials were dominated by reworking of glacial deposits and deposition in marine environments. During the glacial periods, sea level was generally about 150m lower than present sea level, and as such the shore line would have been at the edge of the present continental shelf, about 8-12km offshore.



QUATERNARY GEOLOGY OF THE KAIKOURA PLAINS

Mapped: GMS
Drawn: GMS
Date: 1995

Figure 2.2



LEGEND

Quarternary cover deposits

Tertiary - Jurassic bedrock

GENERALIZED CROSS-SECTION THROUGH THE KAIKOURA PLAINS.

(Section lines shown on figure 2.2)

0 1 2 3 4 Km

FIGURE 2.3.

2.3.2 Quaternary Geology of the Kaikoura Plains

The Kaikoura Plains were formed by the coalescing fans of the Kowhai and Hapuku Rivers and also by fans of the smaller streams draining Mt. Fyffe, Harnetts Creek, the Waimangarara River, Luke Creek, Middle Creek and Floodgate Creek. On the upper Plains area, the fan boundaries are relatively easy to define, marked by a shallow depression at the edge of the two connecting fan surfaces. Lower down on the Plains, however, this shallower depression becomes very indistinct making differentiation of the fan surfaces difficult. This problem is compounded by the similarity of the fan deposit lithologies to one another and the fact that the deposits are often reworked and inter-mixed at the fan boundaries. Figure 2.4 shows Hapuku River fan deposits, and these are typical of alluvial deposits on the Kaikoura Plains.

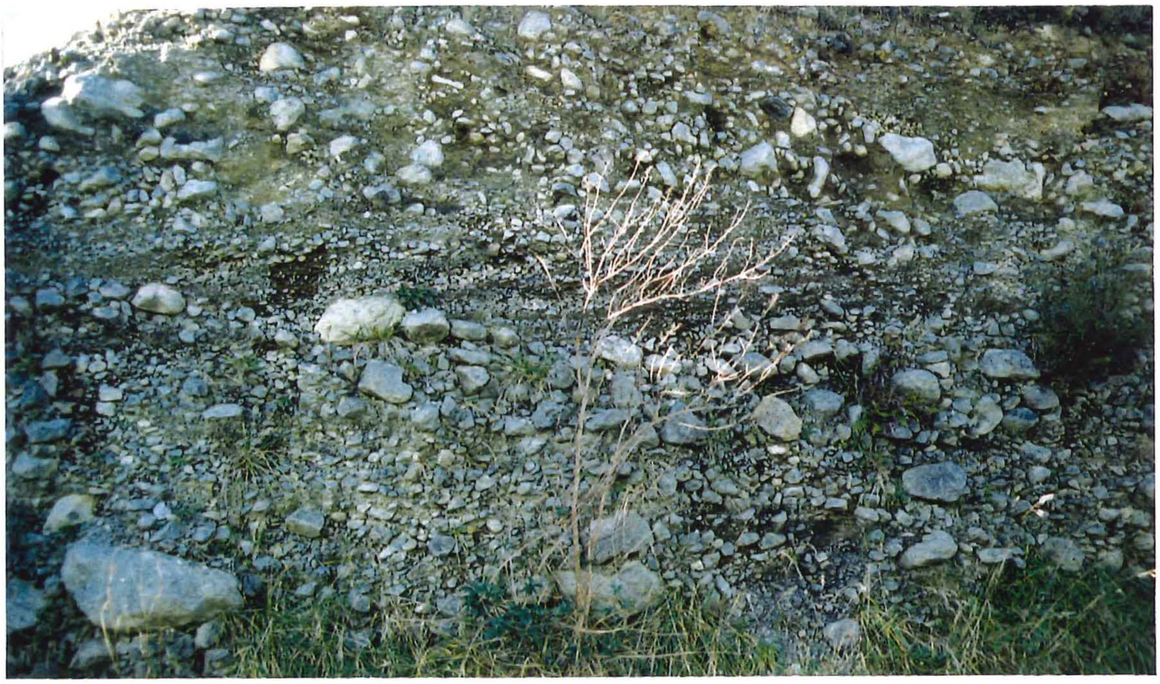


Figure 2.4. Hapuku Fan deposits, which deposits are typical of all the alluvial gravels of the Kaikoura Plains.

The Late Quaternary geology of the Kaikoura Plains as mapped by the author is shown in Figures 2.2 and 2.3. Lithological descriptions of the fan deposits are based on the engineering geological field classification of soils as described by Bell and Pettinga, (1983). These deposits were previously mapped by Lensen (1965), Chandra (1968) and Brown (1988). Chandra (1968) mapped the fan surfaces as Late Pleistocene to Holocene in age based on the development of soil profiles and degree of weathering. Brown (1988) correlated the fan surfaces with the glacial-interglacial sequences mapped in North Canterbury by Suggate (1965). In this study fan surfaces were correlated with a series of terraces preserved on the Hapuku River fan. Ages for the two highest of these fan surfaces, as is discussed later in this section, have been assigned in previous studies by Chandra (1968, 1969) and Brown (1988) as early and late Otiran Glaciation respectively, and for the third highest terrace by Knuepfer (1988) and Van Dissen and Brown (1995) as approximately 6300 years old using weathering rind analysis. Relevant samples and their assigned dates are listed in Appendix III.

Mt Fyffe Fans

The fans of the present day Mt Fyffe streams are in general steeper than those of the Kowhai and Hapuku Rivers due to the high energy environment created by the Hope Fault. Fan deposits of the Mt. Fyffe streams typically consist of unweathered, very poorly sorted, sub-angular to sub-rounded, silty to coarse sandy gravels, often with boulders. The lack of both grainsize sorting and clast rounding exhibited by these fan deposits indicates the close proximity of their source rocks and also the high energy and tectonic activity of the environment from which they were derived. The fans of the Mt. Fyffe streams have resulted from a combination of both fluvial deposition and debris flow deposits

The steeper, high-level fan surfaces which occur along the base of Mt. Fyffe between the Kowhai and Waimangarara Rivers, and above the fans of the present day Mt. Fyffe streams, are thought to be of pre-Otiran Glacial age (Chandra 1969). These deposits lie directly on Tertiary age basement rocks, but exactly how old they are is unknown. These older fan deposits consist of highly weathered (oxidised iron discolouration), very poorly sorted, angular to sub-angular, silty to bouldery gravels. Owing to their steep gradient it could be that these very poorly sorted and highly weathered gravels are the result of periods of rapid uplift along the Hope Fault. As uplift occurred along the Hope Fault the sediment load of the Mt. Fyffe fans increased with the subsequent deposition of material near the fan apices, increasing the gradient of the Mt. Fyffe fan surfaces. Alternatively, the steeper gradient of these older fan surfaces with respect to the younger fan surfaces could be due to post depositional uplift along the Hope Fault increasing the gradient of the fan surfaces by tectonically tilting them.

Kowhai River Fan

The Kowhai River fan, formed by fluvial deposition, displays a more gentle gradient than the fans of the Mt. Fyffe streams. This is likely to be due to distal nature of the fan deposits from their source area. Fan deposits consist of slightly weathered to unweathered, moderately sorted, sub-rounded to rounded fine sandy to bouldery gravels with varying amounts of silt. Clasts consist mostly of light gray, greywacke, sandstones with some dark gray mudstones and light coloured limestones also. Unlike the fans of the Mt. Fyffe streams, a large portion of the Kowhai River fan consists of overbank silts from flood events, these deposits being generally unweathered to slightly weathered, stiff, moderately plastic, bluish gray, clayey to fine sandy silts. The more weathered of these silts are associated with areas of impeded drainage. In the vicinity of the toes of the Mt. Fyffe fans there is bound to be interfingering of Kowhai gravels and flood silts with those of the Mt. Fyffe streams, however the extent to which this has occurred was not able to be determined as the lithologies of the different fan deposits are too similar.

The Kowhai River is perched on its fan and shows predominantly aggradational features as no higher river terraces are present. As such the surface of the Kowhai River fan is made up relatively young deposits (surfaces i, ii, iii & iv), the older deposits having been either eroded and replaced with, or buried by, the more recent material deposited by the Kowhai River and its associated flood events.

Hapuku River Fan

The fan of the Hapuku River consists of slightly weathered, sub-angular to rounded, sandy to bouldery gravels with varying amounts of silt. The gravel clasts of Hapuku River fan deposits are similar to those of the Kowhai River fan, with a predominance of light gray grewacke sandstones with some dark gray mudstones and light coloured limestones. The Hapuku River is entrenched within its fan and as such flood has no significant flood silt deposits, as silts resulting from one flood are removed by the next. The fan of the Hapuku River has been truncated by erosion by the sea after sea levels rose with the retreat of the Otiran Glacial Period starting about 14 000 years ago.

While the Kowhai River is perched on its fan surface, the Hapuku River is quite deeply entrenched into its respective fan. Brown (1988) suggests that this phenomenon may be due to tectonic tilting to the west causing the Kowhai River to aggrade and the Hapuku River to degrade in order to maintain equilibrium. There is substantial evidence of tectonic tilting of the Plains in the Kaikoura area. Chandra (1968) describes the westward tilting of raised shore platforms on the Kaikoura Peninsula and also tilting of fan deposits near the Upper Floodgate Creek in recent time. Van Dissen and Brown (1995) also describe the westward tilting of fan surfaces near the head of the Waimangarara River fan. The results of the geophysical surveys (this study) also indicate the possible westwards tilting of a buried river valley running beneath the Kaikoura Plains.

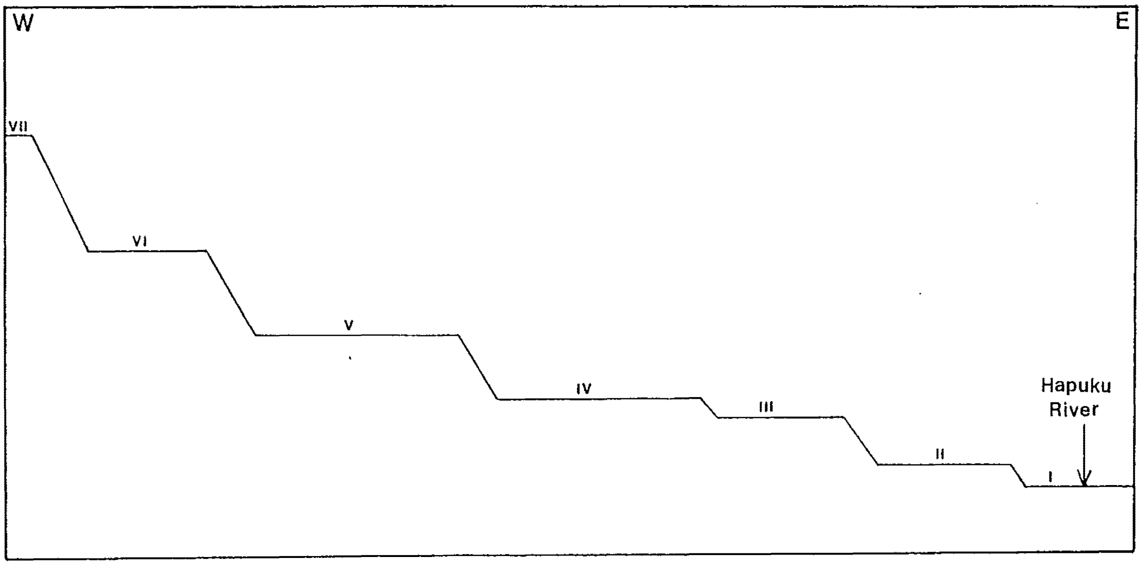


Figure 2.5. Schematic diagram showing the terrace surfaces of the Hapuku River at the head of the Hapuku Fan.

Because it has been entrenching into its fan, the Hapuku River has the most extensive and well preserved series of terraces on the Kaikoura Plains. Seven main terrace surfaces have been identified (Figure 2.5), the lowest and most recent being the present day floodplain, and the uppermost and oldest terrace surface being preserved on the west bank of the Kowhai River as it enters onto the Kaikoura Plains. This uppermost terrace surface (surface vi) has been assigned to early last Glaciation (35000-70000 ka) by Van Dissen and Brown (1995) and Brown (1988) and is correlated with the Windwhistle Formation of North Canterbury (Suggate, 1965). The next highest terrace surface (surface vii) is assigned to late last Glaciation (14 000-35000 ka) and has been correlated with the Burnham Formation (Van Dissen and Brown, 1995 and Brown, 1984). The third highest terrace surface (surface v) was dated by both Van Dissen and Brown (1995) and Knuepfer (1988) as 6290+/-950 ka using weathering rind analysis. Although weathering rind analysis has inherent uncertainties associated with it, this values gives a general age with which to work. The remaining terrace surfaces have not been dated but become younger with decreasing elevation from the Hapuku River. Therefore the youngest five surfaces are post-glacial in age, with the entrenching of the fan surface resulting from the Hapuku River maintaining equilibrium after the truncation of the Hapuku fan by beach processes.

Beach Deposits

The beach deposits consist of a beach ridge or barrier bar north of the Kaikoura Peninsula and stranded beach ridges to the north of the Peninsula. These beach deposits are generally well sorted, well rounded coarse sands to medium gravels. The barrier bar was formed by the deposition of material derived from the erosion and truncation of the Hapuku River fan resulting from rising post-glacial sea levels. Well O31/115 located on the present day beach ridge, near the corner of Mill Road and Beach Road, penetrates 10 metres of beach gravels overlying silt and swamp deposits, indicating a landwards migration of the beach ridge over the deposits which accumulated in the swamp behind it.

The stranded beach ridges are preserved up to 500 metres inland from the coast, northeast of the Kowhai River on the Kaikoura golf course, and southwest of the Kowhai River they are preserved inland from State Highway One. The stranded beaches ridges are the result of the post-glacial rise of sea level truncating the Kowhai River fan, the subsequent deposition of beach gravels and progradation of the coast line are likely to have occurred since sea level attained its present elevation approximately 6500 years ago.

The Lower Plains Area

The lower plains area consists mostly of fluvial silts from flood events originating predominantly from the Kowhai River but also from the Mt. Fyffe streams. These deposits are interspersed, both vertically and laterally, with sands and gravels of old flood channels and minor stream deposits. The silts were deposited by floodwater dammed behind the raised beach ridge between the Hapuku River fan and the Kaikoura Peninsula and have accumulated to significant thicknesses, well O31/156 near Hawthorne Road penetrates 20 metres of these silt deposits. At the base of this layer of silts a sample of wood has been carbon dated at 1724±84 years old (Van

Dissen and Brown, 1995). Swamp and peat deposits also accumulated in this low lying, poorly drained area, boreholes indicate an extensive swamp environment with peat and wood being identified as far west as Red Swamp Road and as far north as Postmans Road.

Relative Chronology

The series of terraces preserved on the Hapuku River fan has been used to correlate and infer relative ages for the fan surfaces of the rest of the Kaikoura Plains. This was done by using aerial photograph interpretation and correlation of the elevations of fan surfaces. Early Otiran Glaciation deposits are very limited, existing only at the head of the Hapuku River fan and near the head of the Waimangarara River fan (surface vii, Figure 2.2). Late Otiran Glaciation deposits are more extensive and comprise most of the Hapuku River fan as well as areas on the Waimangarara River fan and on the higher levels of the fans from Luke, Middle and Floodgate Creeks (surface vi, Figure 2.2). The older age of these fan surfaces, with respect to that of the lower fan surfaces, is indicated by the presence of layers of loess up to several meters in thickness. It is likely that these fans of the Mt. Fyffe streams overlie older fluvio-glacial outwash deposits. The dating of surface *v* (Figure 2.2) of the Hapuku River fan as 6290±950 years old indicates that the majority of the degradation of the Hapuku River fan has occurred in the last 6000 years. This date suggests a period between the formation of surfaces *v* and *vi* during which no significant aggradation or degradation of the Hapuku fan has been preserved.

Beneath the Plains surface, Van Dissen and Brown (1995) have dated samples obtained from the drilling of well O31/156, a groundwater testbore, near Hawthorne Road. The well penetrated 20 metres of fluvial silt and swamp deposits overlying 17 metres of fluvial gravel, sand and silt and then 8 metres of last interglacial marine deposits resting directly on Tertiary baserocks at . The dates obtained are listed in Appendix III. A wood sample obtained from 18 metres below ground, near the base of the silt deposits, was dated at 1724±84 years old, while shells from the beach deposits at 36 and 40 metres below ground were dated from >39 000 to >45 000 years old respectively indicating a probable interglacial deposition. Wood fragments from 36 metres were dated at >50 000 years old, and due to the fragile nature of wood, are likely to be insitu (Van Dissen and Brown,1995). A shell from approximately 17 metres below ground was dated at >48 000 years but due to the presence of the wood sample at 18 metres below ground, this shell is interpreted as being reworked from last interglacial deposits. Due to the interglacial age of the beach deposits and the post-glacial age of the silt deposits it is probable that the intervening gravels are of Otiran Glacial age.

2.4 Geomorphic Evolution

The Seaward Kaikoura Mountain fault block, bounded by large, dextral transcurrent fault zones, was uplifted and eroded to its present configuration during the Pleistocene phase of the Kaikoura Orogeny. It is possible that the uplift and deformation of what is now the Kaikoura Peninsula also started at this time. It is generally thought that the uplift of what was then an island (the Kaikoura Peninsula) occurred discontinuously during the Late Pleistocene and possibly carried on into the Holocene (Chandra, 1969). As the Seaward Kaikoura Range was uplifted it was also being continually eroded. Features such as the Kincaid and Kahutara Hills are the remains of what once were much larger topographic features. A large, shallow bay formed by the Kahutara Hills, the Seaward Kaikoura Mountains and a headland of greywacke to the north of the present day Hapuku River was gradually infilled by the material derived from the erosion of the Seaward Kaikoura Mountains and foothills. Fan building initiated by the uplift and erosion of the Seaward Kaikoura Range during the early Pleistocene continued through the late Pleistocene and into the Holocene. During glacial Periods the river fans would have aggraded relatively fast, and probably connected the Kaikoura Peninsula to the mainland during the later stages of the Pleistocene (Chandra, 1969).

While there is no evidence of glaciation in the Kaikoura region (Suggate, 1965), active tectonism and a harsh periglacial climate during glacial periods meant that the sediment load of rivers and streams was extreme. Both the Kowhai and Hapuku Rivers built large fans towards the Pacific Ocean while the smaller, steeper fans of the Mt. Fyffe streams coalesced and interfingered with each other as well as with the larger fans of the Kowhai and Hapuku Rivers as they, too, advanced and aggraded. Truncation of the Hapuku fan (Figure 2.6) is thought to have started in post-glacial time when the equilibrium between erosion and deposition was altered by rising sea levels. Erosion, longshore transport, and subsequent deposition of material from the fan of the Hapuku River, formed a barrier bar of gravel southward from the Hapuku fan towards the Kaikoura Peninsula. Van Dissen and Brown (1995) suggest that equilibrium between erosion and deposition of this barrier bar was obtained when sea level reached its present level about 6500 years ago, and that the barrier has probably existed since then. Behind this barrier, swamp and estuarine deposits have gradually accumulated over the last 6000 years, interfingering with gravels and sands of the Kowhai River and the Mt. Fyffe streams (Figure 2.7).

Figure 2.6. Sea cliffing of the Kapuku Fan.

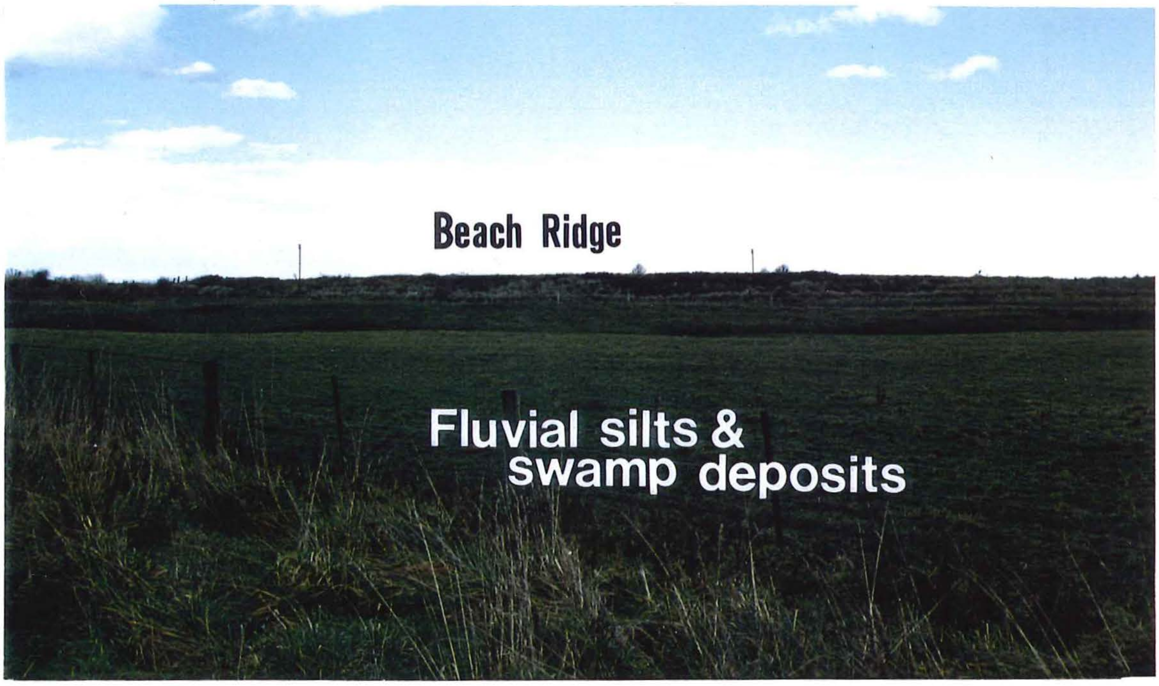


Figure 2.7. Barrier bar resulting from erosion and deposition of Hapuku Fan materials.

Until the advent of European inhabitation in the early 1800's, the area of the Kaikoura Plains approximately below the fifty metre contour consisted largely of swampy wetlands. With the arrival of European settlers, the swamps were drained to allow for both farming and construction to take place. In 1868 a large flood occurred, triggered by a rain-storm from the northwest following an icy southerly storm which had persisted for six days, leaving the country side blanketed in snow. The combined effects of the rain and melting snow was devastating as the sequence of events, which were recorded by Mrs. V. Boyd of Rainford, Kaikoura, illustrate: "The noise of the rain and the sea could not compete with the crashes and roars on the mountains. Whole cliffs collapsed and shingle slipped over the lower land by the thousands of tons. Before this there was no shingle on the flat land.....The heavy swamp halted the shingle after it crossed Mill Road. Mr. David Boyd....had a nice spring of water. It vanished under the shingle and, he had to sink through ten feet of shingle before he got the water. There had been no shingle at all before the flood." The shingle referred to in this passage is inferred to be the arm of Kowhai Gravels extending east of the Kowhai River from the western end of Postmans Road to east of the intersection between Mt. Fyffe Road and Mill Road (Figure 2.2). The more recent flood of December,1993 resulted in the deposition of a smaller arm of gravels east of the Kowhai River just below Kowhai Ford.

Most of the wetlands which remained after the 1868 flood have now been drained and turned to farmland, although it is low-lying and has impeded drainage. A layer of peat has been exposed in Warrens Creek, west of Mt. Fyffe Road, and also in Middle Creek, east of Mt. Fyffe Road. This peat, of undetermined thickness and age, is generally overlain by a 1 to 2+ meter thickness of both gravels and silt.

The presence of a thick layer of swamp and generally fine grained deposits under most of the Kaikoura Plains west of the Hapuku River Fans influence (Figure 2.3) suggests that at one time the Kowhai River may have discharged to the sea through the present day Kahutara River channel, joining it north of the Kahutara Hills. During this time, possibly with only sporadic inputs from the Kowhai River, the thick layer of fine grained swampy sediments accumulated in a predominantly low energy environment.

2.5 Synthesis.

The Kaikoura Plains were formed by the coalescing fans of the Kowhai and Hapuku Rivers and the Mt. Fyffe streams, and overlie a combination of both Tertiary and Torlesse basement rocks. The deposition of these fans has been influenced by alternating glacial and interglacial climatic conditions and the active tectonic environment in which the fan sediments were both derived and deposited. The formation of the Kaikoura Plains has occurred discontinuously since the early Pleistocene uplift of the Kaikoura Ranges began. During the last Glacial period (Otiran) the Kaikoura Plains were more extensive than at the present day but with the retreat of glaciation 14 000 years ago, a decrease in sediment loads of rivers and an increase of sea levels altered the equilibrium between fan deposition and the erosion of material by coastal processes. The result was the truncation of the Hapuku River fan and the subsequent deposition of material derived from this source southwards towards the Kaikoura Peninsula in the form of a barrier bar. Due to different depositional trends the Kowhai River is perched on its fan while the Hapuku River is entrenched in its respective fan. As a result of this older fan surfaces of the Hapuku River have been preserved as they have become above the influence of the Hapuku River flood plain. Conversely only relatively young fan surfaces are present of the Kowhai River fan surface as older deposits have been either buried or eroded by changing river channels and flood events.

3. GEOPHYSICS

3.1. Introduction

To date several geophysical surveys have been undertaken in the Kaikoura area. These include Groundwater Consultants (NZ) LTD (1983), Groundsearch Geophysics (1984,1987), and White and Simpson (1990). Of these geophysical surveys, three employed resistivity techniques while the fourth involved a seismic survey. The seismic surveys carried out in the Kowhai River bed by Groundsearch Geophysics (1987) were aimed at locating any subsurface structures, either river deposits or basement rock, which may have been influencing the river in areas where breakouts have occurred during flooding. The survey by Groundwater Consultants (NZ) LTD (1983) was a trial survey carried out in order to assess the effectiveness of the resistivity survey in the Kaikoura area and to recommend any future geophysical groundwater studies. Groundsearch Geophysics (1984) carried out a resistivity survey of the Waimangarara River fan in an attempt to trace directions and patterns of groundwater flow in the middle reaches of the river. White and Simpson (1990) used resistivity soundings both north and south of the Kaikoura Peninsula to identify subsurface geological structure in the hope of locating a possible groundwater supply for the Kaikoura Township.

3.2 Objectives

The initial geophysical survey was undertaken in order to obtain an idea of the depths to baserock and the thickness of the alluvial cover deposits. It was also of interest to find out if the transient electromagnetic technique employed could distinguish any internal structure within the alluvial cover deposits. The initial survey was undertaken along Survey Line A (Figure 3.1). The results of this first geophysical survey, which are discussed in section 3.4, warranted the undertaking of a second geophysical survey using the same technique, and carried out along Survey Line B.

3.3. Theory and Method

The survey for this study was undertaken using the Geonics Protem-47D transient electromagnetic system in a central loop configuration (Figure 3.2a). A square

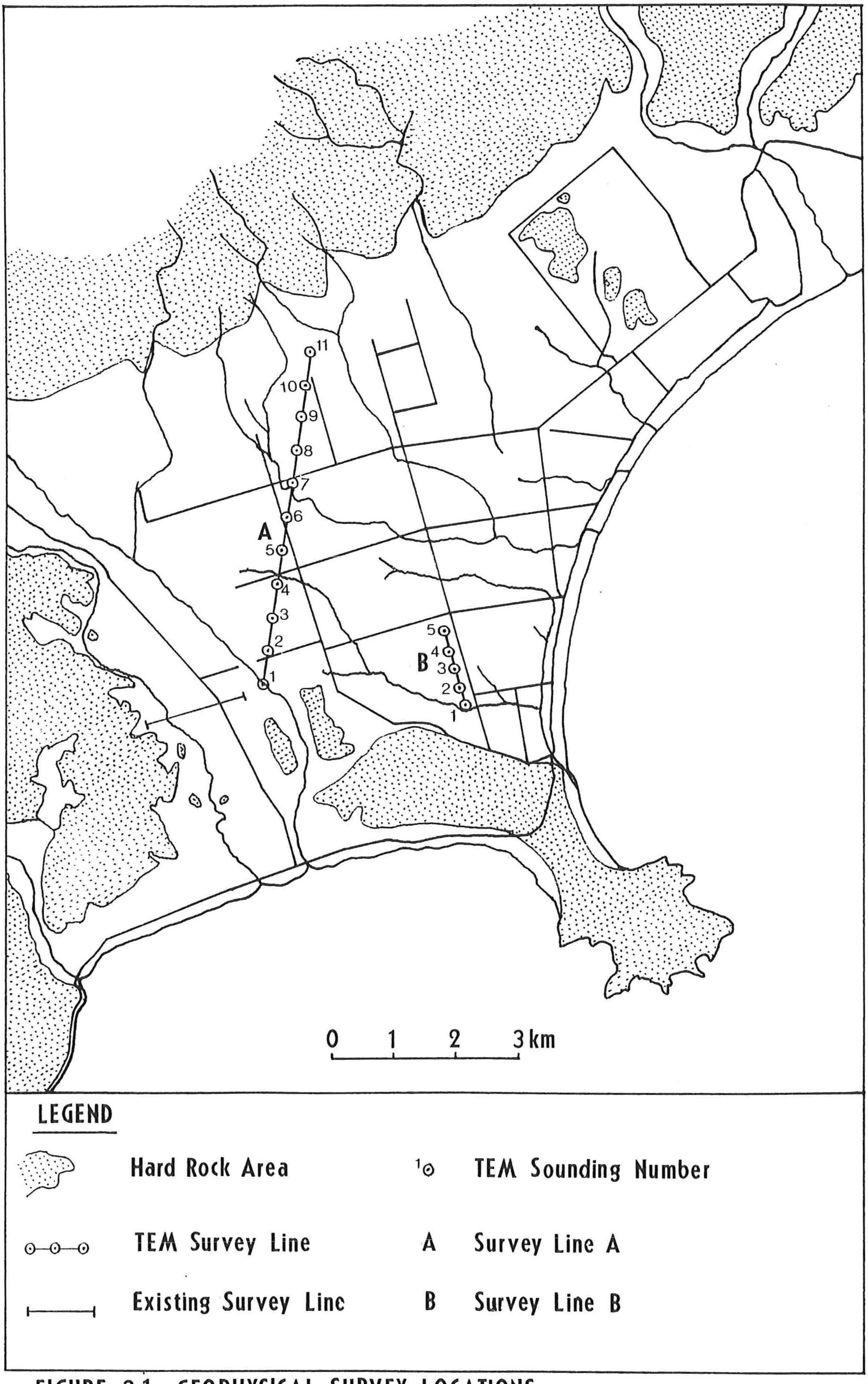


FIGURE 3.1. GEOPHYSICAL SURVEY LOCATIONS.

transmitting loop with 80m side dimensions was used, with the horizontal receiving coil placed at its center (Figure 3.2b).

TEM Theory

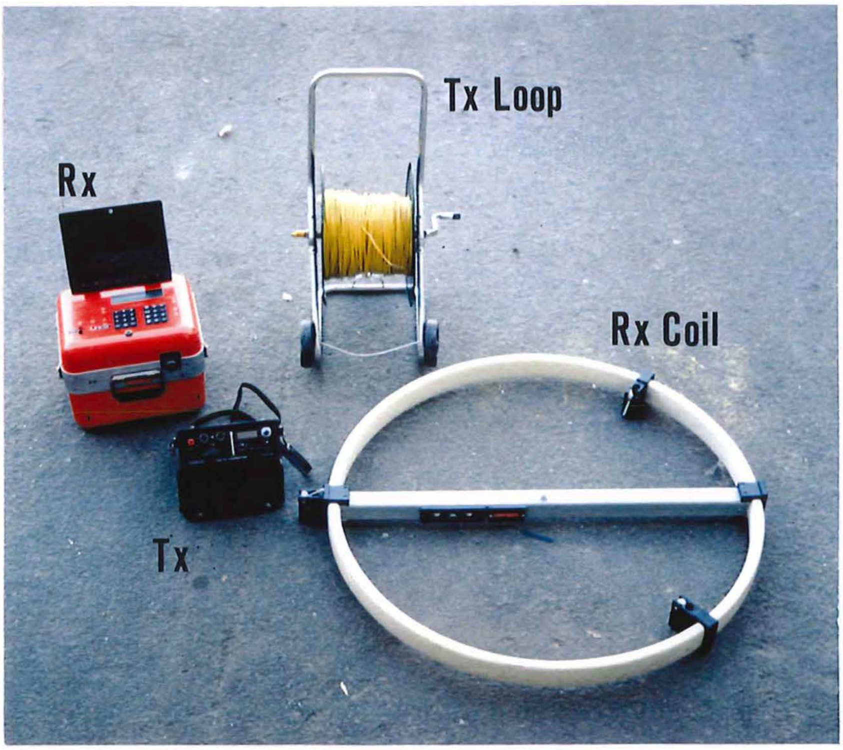
Transient electromagnetism (TEM) operates on a similar principle to resistivity techniques, but rather than applying a current directly to the ground via electrodes, an electromagnetic transient is induced in the ground. This is achieved by applying an electric current through a loop of wire laid out on the ground. The electric current moving through the loop generates a magnetic field. This magnetic field then induces an electrical current in the ground which in turn creates a secondary magnetic field. When the current in the wire loop is switched off, the receiver records the amplitude of the induced current by measuring the decay of the magnetic field as it moves out and away from the transmitter loop (Figure 3.3). The current is switched on and off in a matter of milliseconds and the decaying magnetic field is measured over a number of intervals and the results stacked to eliminate random background noise.

The depth of penetration achieved by this technique is governed by the electrical properties of the ground and the strength of the induced electromotive force, which in turn is proportional to the size of loop used and the current applied to it.

TEM responds to changes in electrical properties within the ground; however, these changes do not necessarily correspond with changes in geology. If the ground is too resistive, the signal may be lost. In contrast the presence of a highly conductive layer may mask any underlying features.

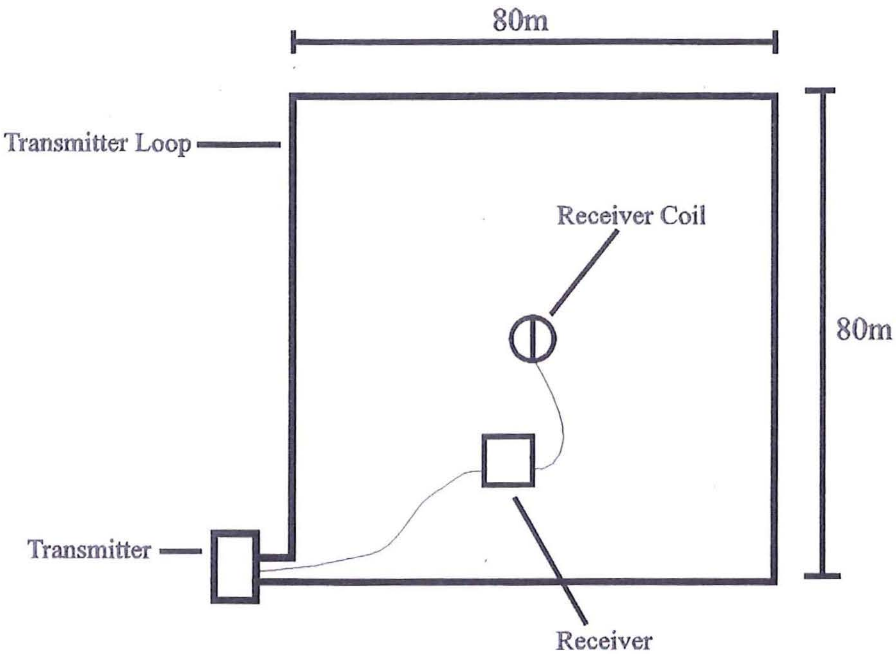
Modeling

The initial geoelectric section carried out along the Survey Line A shown in Figure 3.1, using a series of vertical soundings at approximately 500m intervals, depending on topography and obstructions. The second survey was carried out along Survey Line B at approximately 300m intervals. The collected data was processed using the transient electromagnetic data interpretation software, Temix-GL™ v.3.0 (Interpex, 1993). A series of layered earth models were compared with the data by applying a forward calculation to the model parameters (depth and apparent resistivity) until an acceptable fit was obtained. The forward calculations generate a synthetic curve to compare with the real data. Once an acceptable model is found, inverse iterations are performed on the model parameters in order to further refine the model, so that it



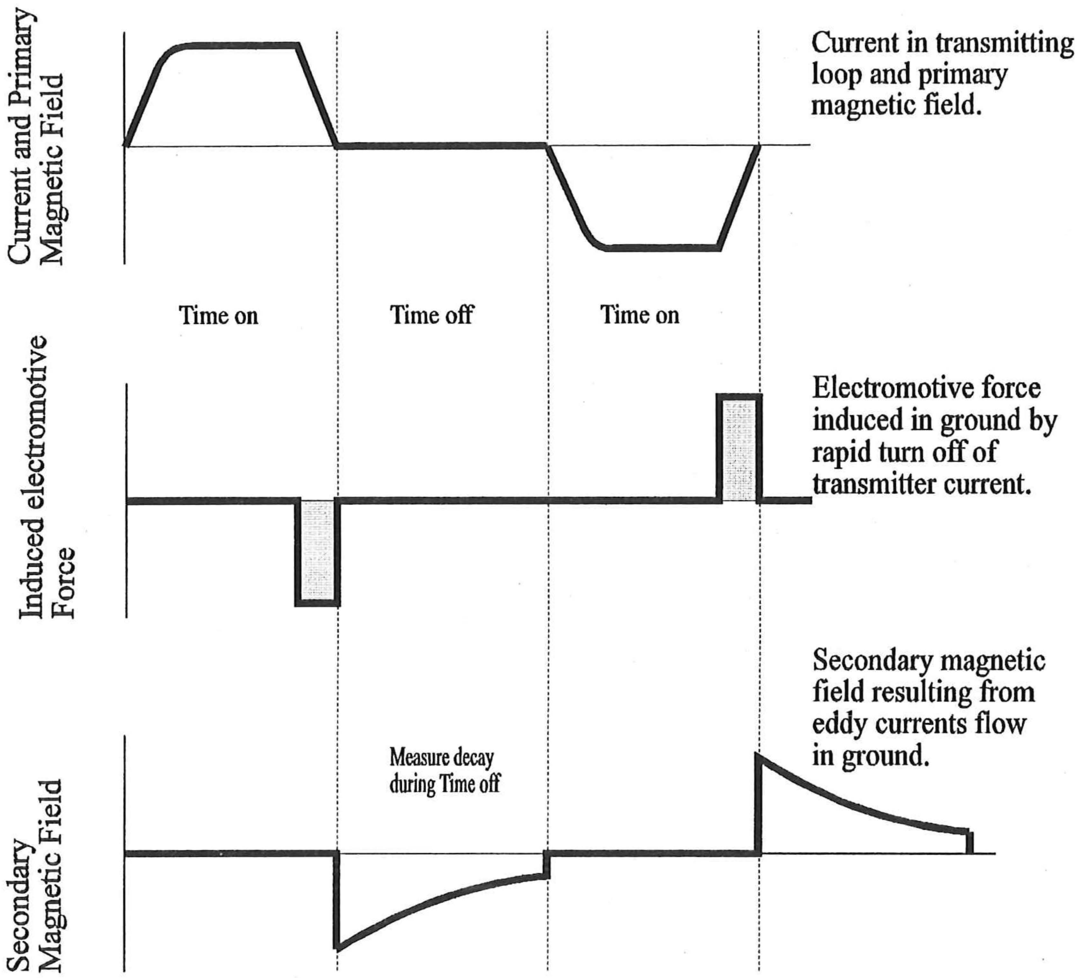
Tx	Geonics electromagnetic transmitter.
Tx loop	Transmitter loop.
Rx	Protem-47D T.E.M. receiver.
Rx coil	Receiver coil.

a. T.E.M. equipment.

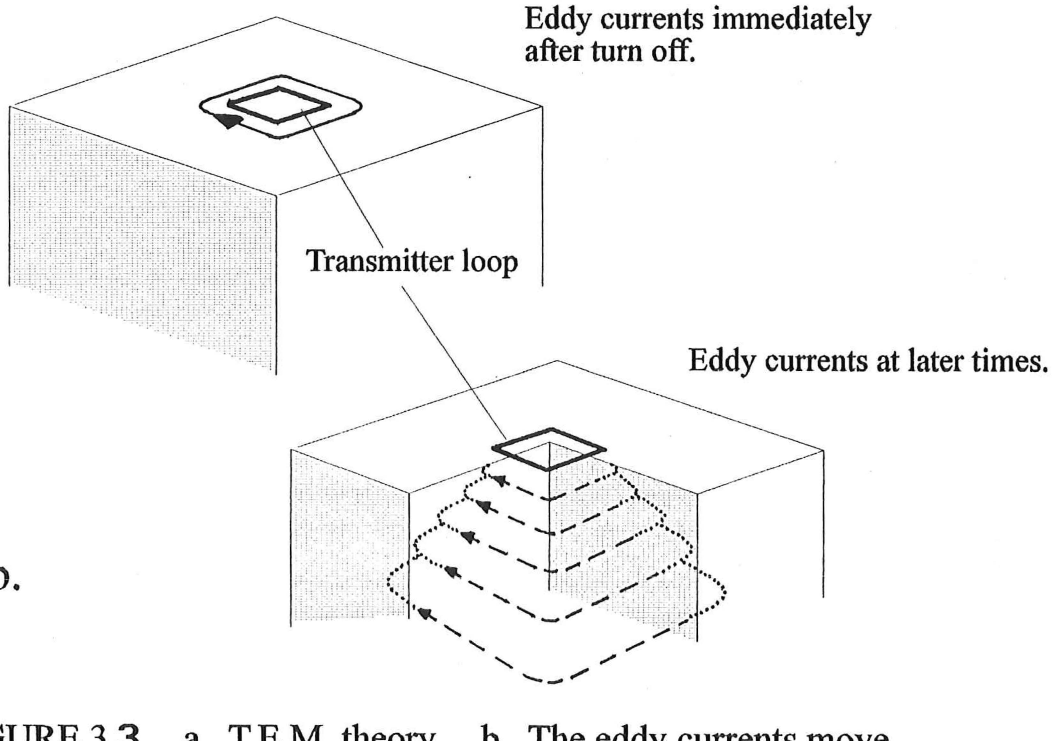


b. Central Loop Configuration.

FIGURE 3.2 T.E.M. Equipment and Set-up



a.



b.

FIGURE 3.3 a. T.E.M. theory. b. The eddy currents move out and away from the transmitter loop. (Source: McNeill, 1990) matches the real data as closely as possible. Each inverse iteration performs an iteration of ridge regression inversion using the current model as a starting point, thus minimizing the least squares error between the data and the synthetic curve.

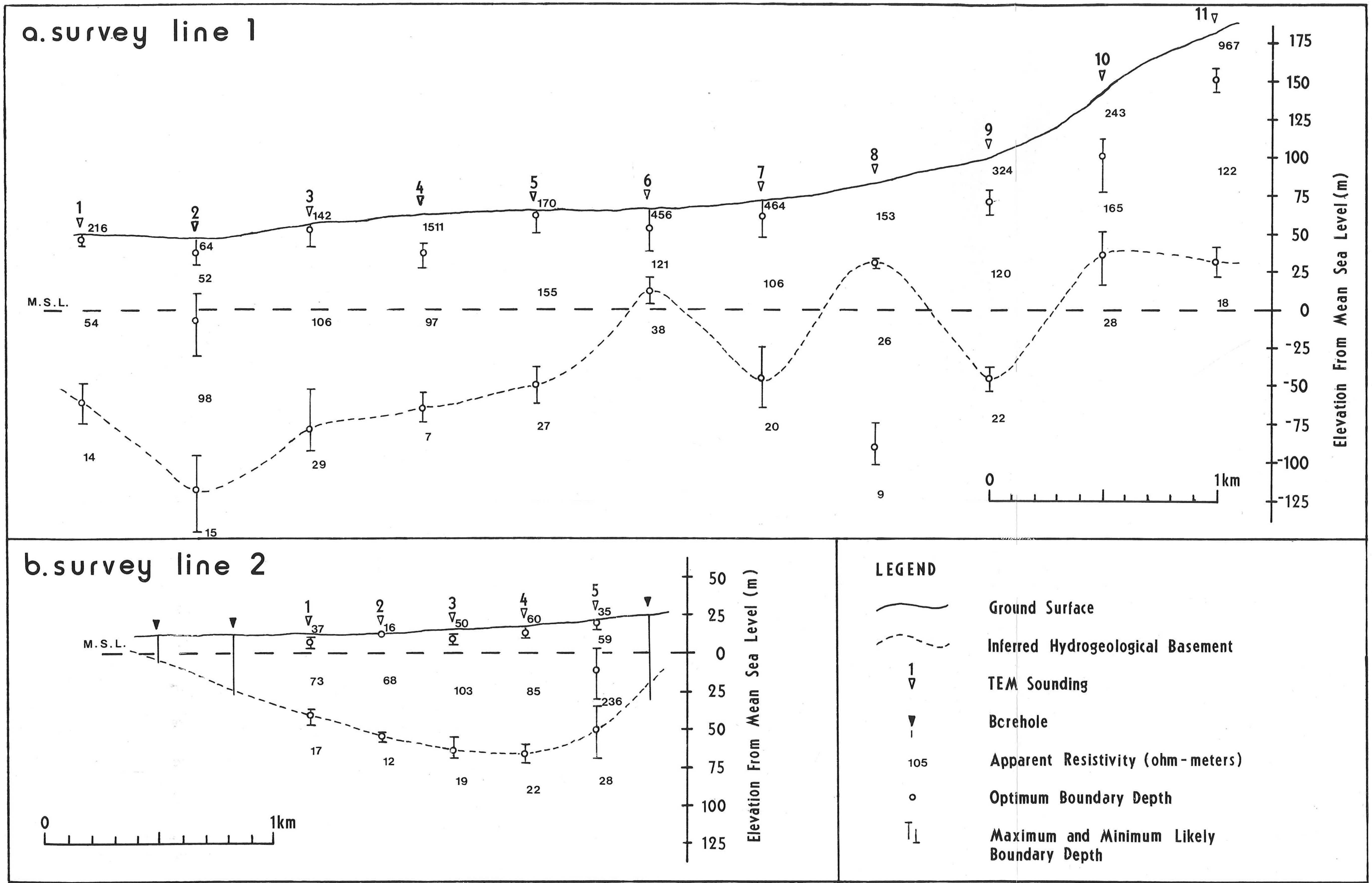
Once a best fit model was obtained, to determining how closely constrained the model was, the equivalence for each model was analysed. The analysis involves finding models with similar fitting errors as the best fit model, which is done by setting an error threshold of at least 1.2 times the best fit error and then varying the model to find the variation that produces a fit equal to or less than the error threshold. This is done twice for each model parameter: for the upper boundary and for the lower boundary.

Smooth modeling of the data was also undertaken. Smooth modeling estimates the sub-surface apparent resistivity profile by creating a model with a given number of layers and a maximum thickness. in this case fifteen layers were used with a combined maximum thickness of 200m. The computer starts off by assigning the fifteen layers with equal resistivties and thickness and then performs numerous iterations of ridge regression inversions until the fitting error of the model cannot be improved by more than 1% per iteration. Smooth modeling operates by adjusting the layer resistivities of the model to fit the data and then adjusting the layer thickness proportionally to the layer resistivity, thus a low resistivity layer would be modeled thicker than a highly resistive layer. Smooth modeling can be useful in determining a starting model when no other subsurface information is available.

3.4. Interpretation and Results

3.4.1. Initial Survey

The electromagnetic soundings yield apparent resistivities against depth within the earth; once obtained, the interpretation of these soundings is relatively straightforward, and is helped when borehole data are available for calibration. The TEM survey data and models are presented in Appendix IV. The interpreted results of the first survey are shown in Figure 3.4a. Although none of the current boreholes penetrated deep enough to be of much value, the depths to Tertiary and Torlesse baserocks obtained were consistent with the earlier resistivity survey of Groundwater Consultants (N.Z.) Ltd. (1983), which was carried out on a line running between the Kahutara Hills and the Kowhai River below Middle Ford (Figure 3.3).



APPARENT RESISTIVITY SECTIONS FROM TRANSIENT ELECTROMAGNETIC SURVEYS.
FIGURE 3.4.

The boundary depths were taken from the best fit model for that site while the maximum and minimum probable boundary depths were obtained by taking the upper and lower extreme values calculated for that site when analysing the equivalence for the best fit model.

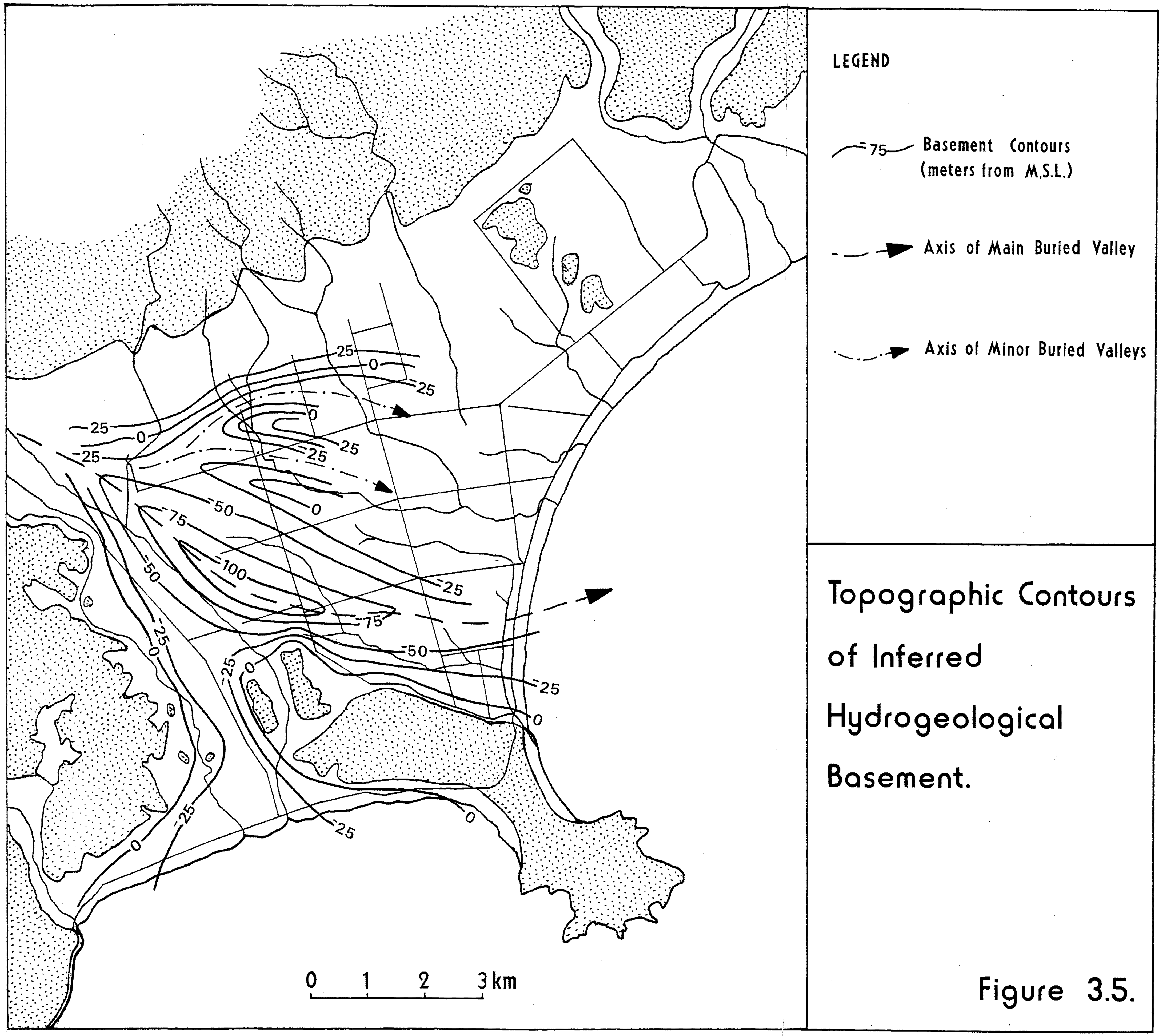
The results show clearly the relationship between the basement rocks and the alluvial cover deposits as well as showing the buried topography of the Tertiary/Torlesse basement rocks. It is likely that these topographic features are the result of fluvial activity during glacial periods when sea level was much lower than the present day. Alternatively the basement rock topography could be tectonically influenced displaying structural features similar to those exposed on the Kaikoura Peninsula. Although no internal structure within the alluvial deposits were identified the survey did indicate a substantial thickness of unexplored gravels indicating the possibility of undiscovered aquifers beyond the deepest existing borehole penetration to date (c.50m). Of particular interest is the baserock low indicated beneath sounding number two. This sounding indicated baserock to be at an elevation of approximately 120±20m below sea level at that location, indicating a possible thickness of gravels in the vicinity of 170m.

From a groundwater exploration point of view it was of interest to see whether or not the major basement low indicated in the geoelectric section (Figure 3.4a) was in fact a buried valley, and whether or not it extended southwards past the Ludstone Hills, Kaikoura Peninsula area. The possibility that the buried valley identified in the initial survey exits to the sea to the west of the Kaikoura Peninsula has been ruled out by the resistivity survey by Groundwater Consultants (N.Z.) Ltd. (1983) which indicates that baserock is too shallow (approximately 50m below sealevel) through the area between the Kahutara Hills and the low hills constraining the Kowhai River below Kowhai Ford. A well near the corner of Mill and Mt. Fyffe Roads (O31/0005) intercepts baserock at a reduced level of about 25 meters below sea level putting a further constraint on the possible location of the buried valley. Thus if the buried valley did exit to the sea to the north of the Kaikoura Peninsula it would have to lie either to the north or south of well O31/0005. The natural lay of the land and surround hardrock features suggested that the buried valley would more likely lie to the south of well O31/0005 between Mill Road and the Ludstone Hills. Further constraints on depth to basement from bore hole data in the vicinity of Mt. Fyffe Rd.(O31/0199,O31/0156) suggest the basement low must lie approximately between Hawthorne Rd. and Mill Rd. The second geophysical survey line, therefore, was sited over the predicted location of the buried valley and was designed to either confirm or deny the presence of this trench.

3.4.2. Secondary Survey

The second geophysical survey was carried out along a line parallel to Mt. Fyffe Road from Hawthorne Road to Mill Road (Survey Line B, Figure 3.1). A buried valley was again identified in this survey although not as deep as expected (Figure 3.4b). There are various possible explanations to explain this deepening of the valley floor inland: 1, the depression identified in the second geophysical may in fact be a separate feature from that identified in the first survey, with the valley identified in the first survey exiting to the coast further northwards than the second survey location. However, this would require the buried valley to undergo a change in direction of approximately 90° from a general southeast trend to a general northeast trend; 2, the buried valley of Survey Line A exits to the sea west of the Kaikoura Peninsula following the path of the present Kowhai River between the hills of outcropping Tertiary sediments to the northwest of the Ludstone Hills. This option is unlikely as the depth required between the two hills means that the valley sides would have to have an average slope of at least 45° for there to be a seawards gradient of the valley floor; and 3, the valleys identified in both surveys are in fact the same feature but the valley has been tectonically tilted towards the west, thus resulting in the inland gradient of the valley floor. As already outlined in the previous chapter (section 2.3.1) there is substantial evidence for westwards tilting in the Kaikoura area, including the westwards tilting of raised shore platforms on the Kaikoura Peninsula, and of various fan surfaces high up on the Kaikoura Plains. To the writer this third option is the most consistent with the physical and tectonic setting of the Kaikoura area, and has been accepted as the most likely explanation. Although the depth of the buried valley in this second survey still indicates the presence of a considerable thickness of previously unexplored sediments.

From the results of both surveys a topographic map of baserock has been constructed (Figure 3.5). The main buried valley is the dominant feature running beneath the Kaikoura Plains in a general North-West to South-East trend, bounded to the South by the Ludstone Hills and the Kaikoura Peninsula. Two smaller valleys are also identified further up the plain. However, Survey Line Two did not extend northwards enough to determine their extent.



Topographic Contours of Inferred Hydrogeological Basement.

Figure 3.5.

Another outcome of the geophysical surveys was the identification of a site for the drilling of an exploration and observation well. The main buried valley identified in both surveys is considered to be the best location in which to find previously unknown aquifers. Ideally it was also of interest for an exploratory bore to penetrate the whole thickness of sediments overlying baserock in order to have some physical constraints on the geophysical calibration and interpretation. With this in mind a location for the drilling of an exploration bore was chosen which allowed for penetration of the entire thickness of gravels infilling the buried valley to the base of the buried valley, and which also allowed it to be correlated with the interpretation of Survey Line Two. However due to funding problems the exploratory bore was unable to be drilled.

3.5 Synthesis

The employment of the transient electromagnetic surveys in this study has resulted in the determination of depths to the Tertiary/Torlesse base rock along the two geophysical survey lines used in the study, and thus have provided values for the thickness of the alluvial cover deposits of up to 170 metres. However the geophysical survey was unable distinguish any internal structure within the alluvial cover deposits. Subsequent extrapolation of this geophysical data, and correlation with other constraints on depth to baserock such as well logs and baserock outcrop locations, has allowed depths to baserock to be inferred for a significant portion of the Kaikoura Plains. These results indicate the presence of a substantial and unexplored groundwater resource, but this resource has yet to be proved by the drilling of an exploratory bore. The drilling of an exploratory bore was initially to be included as a part of the present study, but due to a lack of funding it had to be abandoned.

4. HYDROGEOLOGY

4.1 Introduction

Given the nature of alluvial fan systems, the boundaries of specific aquifers are often hard to define, in terms of both thickness and lateral extent. An aquifer system which exists over an area may be comprised of aquifer materials derived from different sources, and subsequently, may contain water originating from different river and infiltration sources. Consequently it is often necessary to simplify geological and hydrological relationships in order to be able to identify the way in which an aquifer system behaves and interacts with both other aquifers and external influences such as river systems and rainfall infiltration.

Previous studies of the Kaikoura groundwater system (Brown and Taylor, 1974; Brown, 1988) identified the presence of three aquifers as follows:

1. Water Table Aquifer

2. Non-flowing Artesian Aquifer

3. Flowing Artesian Aquifer

The water table aquifer more or less underlies the whole of the Kaikoura Plains at depths of just below ground level near the coast to 20 m or more inland around Postmans Road. The confined aquifers are more limited in their extent than the watertable aquifers and occur at depths of around 20 to 40+m below ground level. The water table aquifer and the confined aquifers are generally separated by a layer of swamp and flood silt deposits interspersed with varying amounts of gravels. Brown (1988) gives the following evidence to support his theory that the flowing and non-flowing aquifers are separate aquifers: Firstly, there is a contrast in water levels of wells in the flowing and non-flowing aquifers for wells at similar ground levels and depths, which implies that there is a hydraulic discontinuity between the wells and therefore the aquifers; Secondly, driller's pump tests indicate that the non-flowing artesian aquifer has a much greater permeability than the flowing artesian aquifer; Thirdly, there is a difference in the groundwater chemistry and also in isotopic data, recharge paths of each aquifer as indicated by deuterium, tritium and oxygen 18 isotopes (Brown & Taylor, 1974; Brown, 1988). However, there is little in the way of geological evidence from well logs to differentiate between the flowing and non-flowing artesian aquifers.

4.2 Aquifer Description

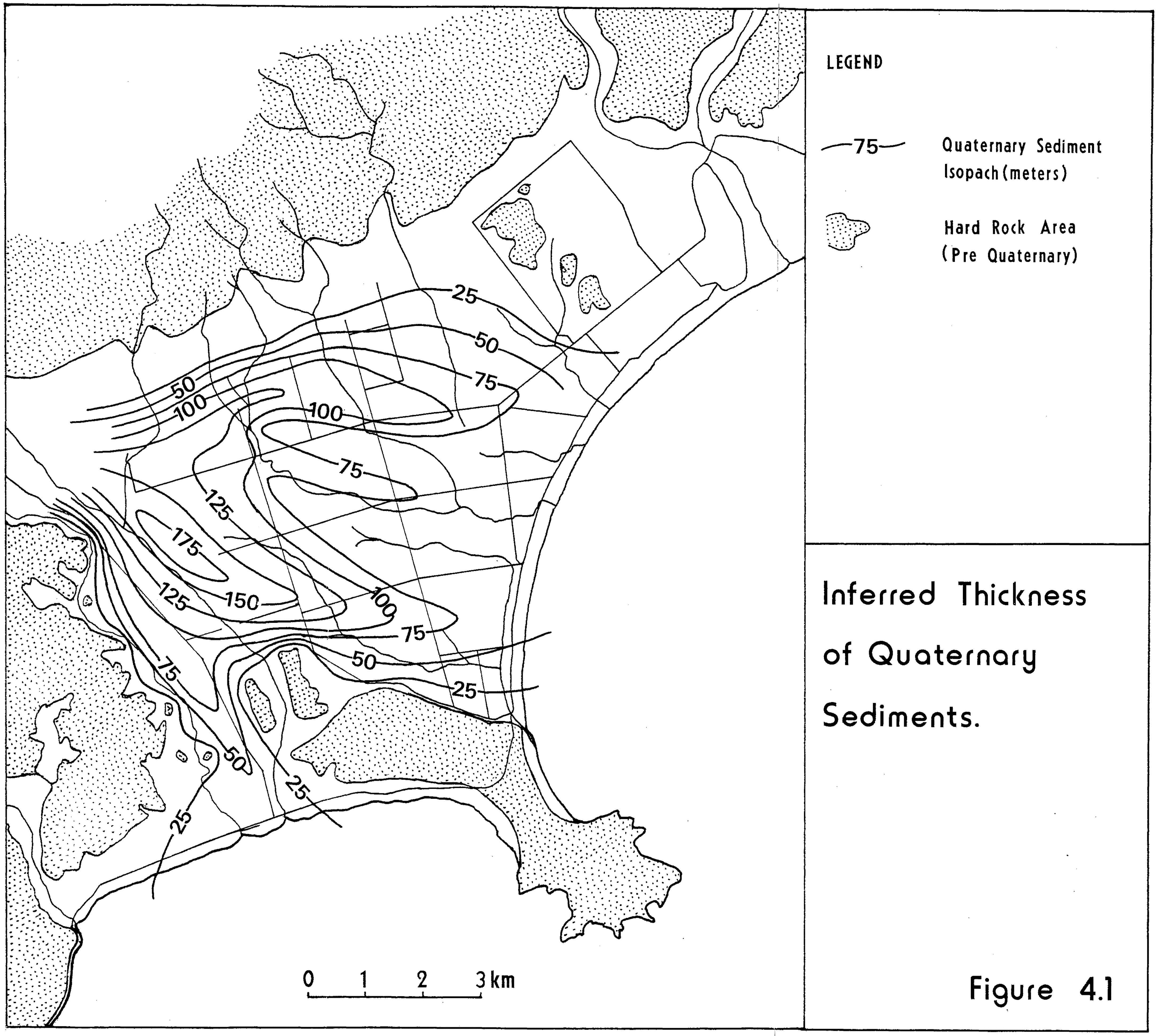
4.2.1 Groundwater Reservoir.

The Quaternary sediments overlying Tertiary, and older, basement rocks are the only economic source of groundwater in the Kaikoura area, and therefore the Quaternary sediment-hardrock interface is defined as the hydrogeological basement. Depth to basement varies greatly, with basement rocks outcropping to form the northern and western extent of the Kaikoura Plain, and also the Ludstone Hills and Kaikoura Peninsula at the southeastern extent of the plains. Geophysical surveys indicate that depth to basement may be as much as 140m in places in the vicinity of Kowhai Ford Road (Figure 3.4a). An isopach map of the inferred thickness of Quaternary sediments is given in Figure 4.1. Within these alluvial deposits aquifers may be distinguished by the presence of saturated geological units of high permeability associated with poorly graded, coarse grained sediments with the ability to yield a usable quantity of water for a sustained period of time. In the context of the Kaikoura Plains this means the presence of poorly graded (well sorted) alluvial gravels and sands

4.2.2 Aquifer Determination

The Canterbury Regional Council has records of some 260 wells in the Kaikoura area, although a large proportion of these records do not have accompanying well logs. However, those well logs which were available were used in identifying and interpreting the aquifer systems of the Kaikoura Plains. All wells and boreholes referred to are a part of the Canterbury Regional Council's wells database.

In the higher plains area above Postmans Road formed by the coalescing fans of the Mt. Fyffe streams, aquifer boundaries are hard to define and correlate between boreholes, there are no extensive predominantly coarse or fine grained layers. As such the aquifers of the upper plains area are predominantly unconfined to semi-confined with irregular confining layers comprised of fluvial sillts and, in places loess, of limited areal extent.



Inferred Thickness of Quaternary Sediments.

Figure 4.1

Borehole data on the Hapuku River is very limited, but exposure along the sea cliffing and in a deep stream cut ravine northeast of Skevingtons Road (NZMS 260 O31/678-735) suggests an unconfined aquifer (approximately 10m thick) comprised of Otiran Glacial age fluvial gravels, and confined aquifer of gravels of undetermined age separated by a confining layer of a stiff blue silty clay.

On the central Kaikoura Plains below Postmans Rd. the aquifer system is mostly confined although an unconfined aquifer is present in the vicinity of the Kowhai River and its flood channels. Over the rest of the lower plains area there is a surface confining layer consisting of low permeability silts of over-bank flood and swamp deposits. However this surface confining layer is penetrated by decaying tree roots and branches which in places may provide passage for the vertical seepage of water to and from the surface (Figure 4.2).

Figure 4.2 Decaying tree roots and branches provide a passage for the vertical seepage of water.

4.2.3 Aquifer Nomenclature.

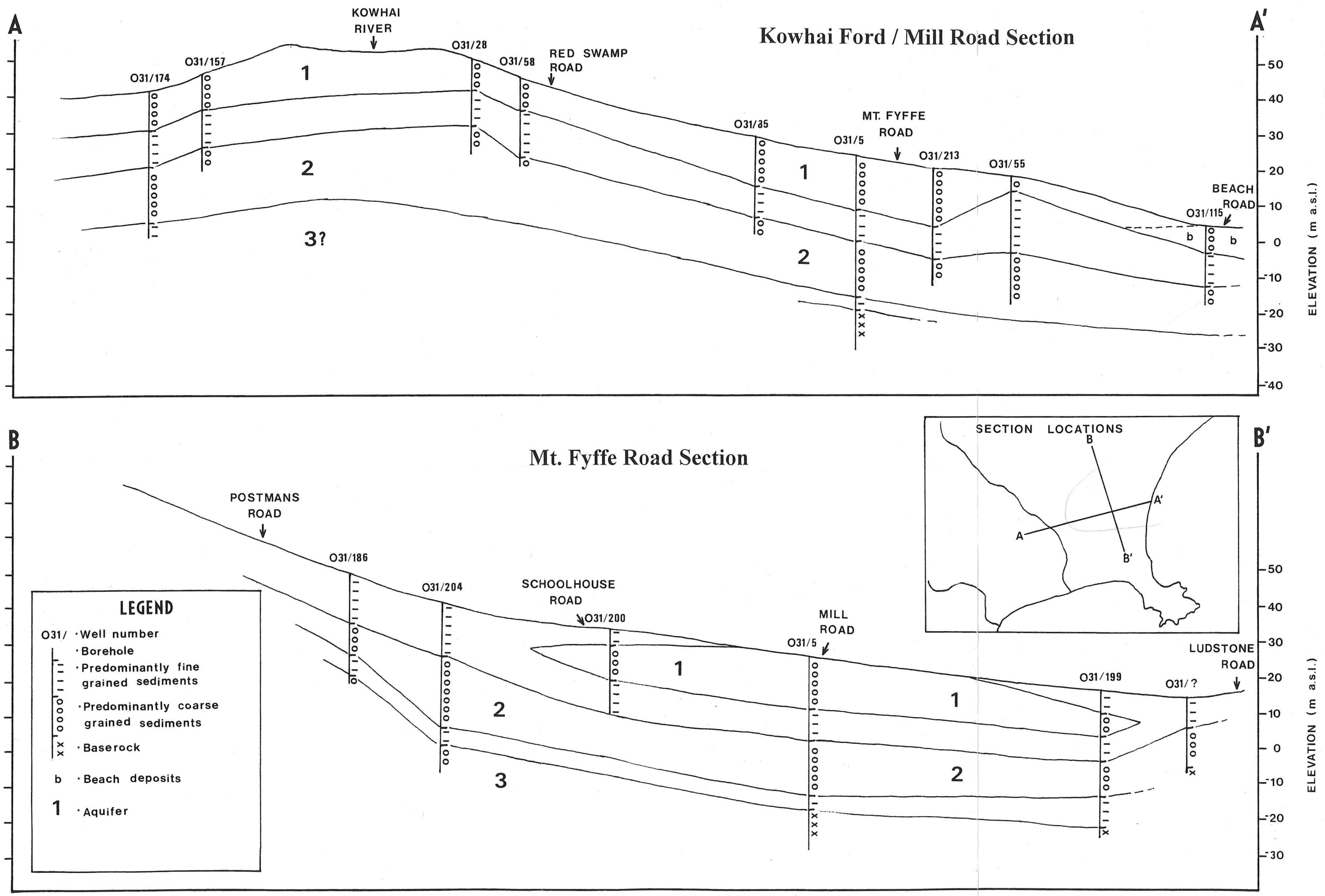
Beneath the lower Kaikoura Plains three main aquifers and two main aquitards have been identified by correlating sequences of predominantly coarse grained sediments (potential aquifers) and predominantly fine grained sediments (aquitards) between boreholes. The naming of the aquifers is based primarily on their vertical sequence, from the ground surface downwards. A schematic cross section of the aquifer system present beneath the Kaikoura Plains is given in Figure 4.3. However, these predominantly coarse or fine grained deposits are not of uniform grainsize and do not indicate the exact location of an aquifer or aquitard, they are only used to indicate the likelihood or not of the presence of water bearing strata.

Aquifer 1

Aquifer 1 is mostly unconfined apart from some localised surface confining layers of flood silt deposits. Aquifer 1 exists over most of the upper plains, including the Hapuku River fan, and in the alluvial deposits of the Kowhai River fan. Aquifer 1 is generally consistent with Brown and Taylor's (1974) 'Water Table Aquifer'. Aquifer 1 is very variable in thickness ranging anywhere from 2 metres to 20 metres thick.

Aquifer 2

Aquifer 2 is a confined to semi- confined aquifer beneath the central Kaikoura Plains and also to the west of the Kowhai River and Kaikoura Peninsula. It is also suspected that Aquifer 2 extends north and east into the Hapuku River fan, however there is no borehole evidence to support this, although a layer of stiff blue silty clay separating silty gravel deposits was observed at the base of a deep stream cut ravine near Skevingtons Road. Aquifer 2 includes both of Brown and Taylor's (1974) Flowing and Non-flowing Artesian Aquifers. The different isotopic analyses obtained by Brown and Taylor (1974) for these 'two' aquifers is explained as being the result of different recharge sources within the same aquifer. On the lower plains in the vicinity of the Kowhai River, Aquifer 2 is subject to mostly Kowhai River recharge; on the upper plains, recharge to Aquifer 2 is predominantly from Mt. Fyffe drainage, with the subsequent mixing of these two waters of different origin within the aquifer. Brown and Taylor's distinction between a flowing and non-flowing artesian aquifer was also based on too few samples to be conclusive. Near the coast northeast of the Kaikoura Peninsula there is a lowering of aquifer transmissivity within Aquifer 2, the result of this is that groundwater movement is considerably slower and hence groundwater in this situation is older than that in parts of the aquifer with higher transmissivity. Elevated water levels in Brown and Taylor's 'Flowing Artesian Aquifer' can be explained as the effect of groundwater mounding due to recharge from the Kowhai River (see section 4.6.3). The effect of this is to produce elevated water levels down gradient of the recharge area which gradually reduce to



Schematic Sections Showing Simplified Aquifer Structure

Figure 4.3.

background water levels with increasing distance from the recharge source. This effect can be observed from the piezometric contours of Figure 4.12.

The presence of Aquifer 3 has only been indicated by a few boreholes and it remains unexploited. There is too little borehole data to determine either the vertical or lateral extent of this aquifer although it is suspected to be largely constrained within the main buried valley identified in Chapter 3. The possibility of the existence of further aquifers at depth within this buried valley should not be over looked. Ideally an exploratory borehole should be drilled through the alluvial deposits which infill this buried valley in order ascertain the presence of any further aquifers.

4.3 Aquifer Performance

4.3.1 Specific Capacity

The specific capacity of a well is defined as the discharge of a well per unit drawdown of the water level in that well. Generally speaking specific capacity is not a constant due to a number of reasons that include (Bouwer, 1978): 1. drawdown in a well generally continues to increase during pumping even if only fractionally during later times, thus specific capacity decreases with continued pumping; 2. well losses vary proportionally to discharge, therefore the specific capacity of a given well will decrease with increasing discharge; and 3. in unconfined aquifers drawdown may increase with respect to discharge as drawdown of the watertable reduces transmissivity.

However, Driscoll (1989) has shown that the specific capacity of a well operating under confined conditions is constant for any pumping rate so long as the aquifer is not dewatering. Values for specific capacity should be treated warily as their accuracy cannot always be taken for granted, when comparing values of specific capacity one of the main problems is the duration of pumping used to determine the values. Driller's well tests tend to be of only one or two hours duration and therefore tend to over estimate values.

In the Kaikoura area 26 values of specific capacity are known and these are presented in Appendix V. An attempt was made at determining any spatial or aquifer specific trends in specific capacity values but no clear trends were obvious, indicating that perhaps more values were required to obtain definitive results.

Specific capacity data can be used to estimate transmissivity by determining the relationship between transmissivity and specific capacity, from which subsequent values for transmissivity can be inferred from the specific capacity values. But there was no strong correlation between the values for transmissivity and specific capacity indicating that too few values for transmissivity are known in the Kaikoura area to determine a reliable relationship with specific capacity values.

4.3.2 Pump Testing

Pumping test data for wells on the Kaikoura Plains is extremely scarce, with only three known wells having been pump-tested before the present study. Aquifer characteristics obtained from pump tests are presented in Table 4.1. Two constant rate discharge pump tests were carried out by the writer and CRC staff in order to obtain values for aquifer transmissivity (T) and storativity (S). Aquifer transmissivity is defined as flow through a unit width of aquifer under unit hydraulic gradient and as such is a measure of the aquifer's ability to transmit water (Figure 4.4). Aquifer storativity or storage coefficient is a measure of the amount of water which will drain from a unit area of aquifer when the water level drops by one meter (Figure 4.5).

A constant discharge pump test involves pumping a well at a constant rate of discharge and recording the drawdown of the water level in the well, and also its recovery once pumping has stopped. Water levels are also monitored in one or more observation wells at known distances (radii) from the pumped well. Monitoring of water levels is usually continued even though water levels have fully recovered in order to identify any background water level fluctuations which may have an effect on the analysis of pump test data. As the well is pumped the water table or piezometric surface around the well is lowered, with the effect lessening further away from the pumped well. This effect forms what is known as the cone of depression or cone of influence around the pumped well (Figure 4.6). The observation wells are used to help in determining the extent of this cone of depression, which is directly related to the aquifer transmissivity and storativity.

The theoretical analysis of pump test data is based on five assumptions as to the physical characteristics of the aquifer, and these should be met as closely as possible. The general assumptions are as follows (Kruseman and De Ridder, 1979):

1. The aquifer is of infinite lateral extent.

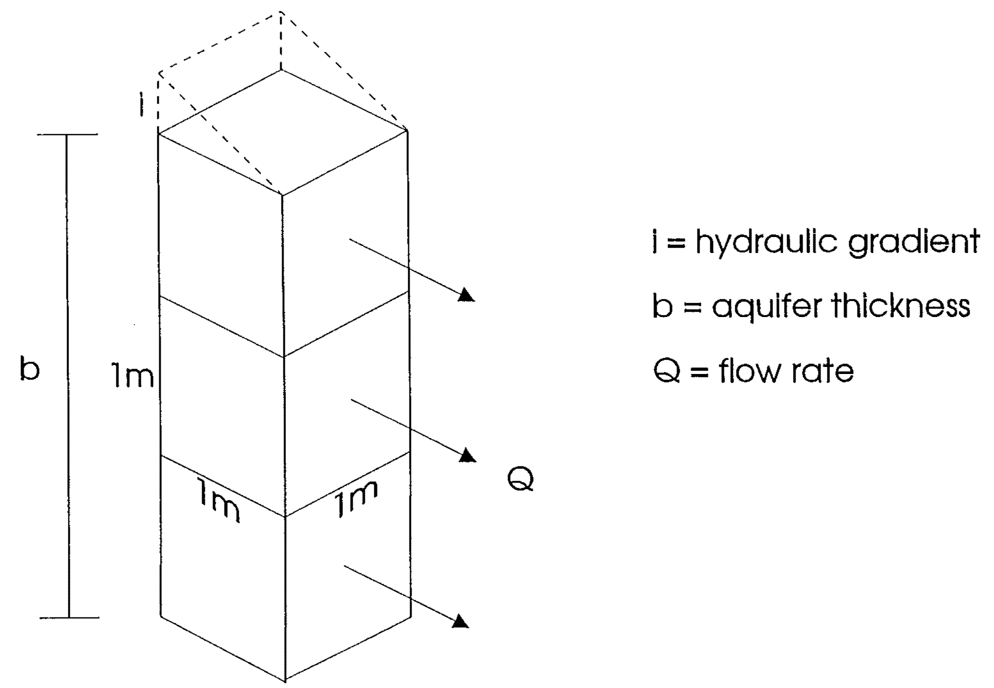


FIGURE 4.4. Aquifer Transmissivity.

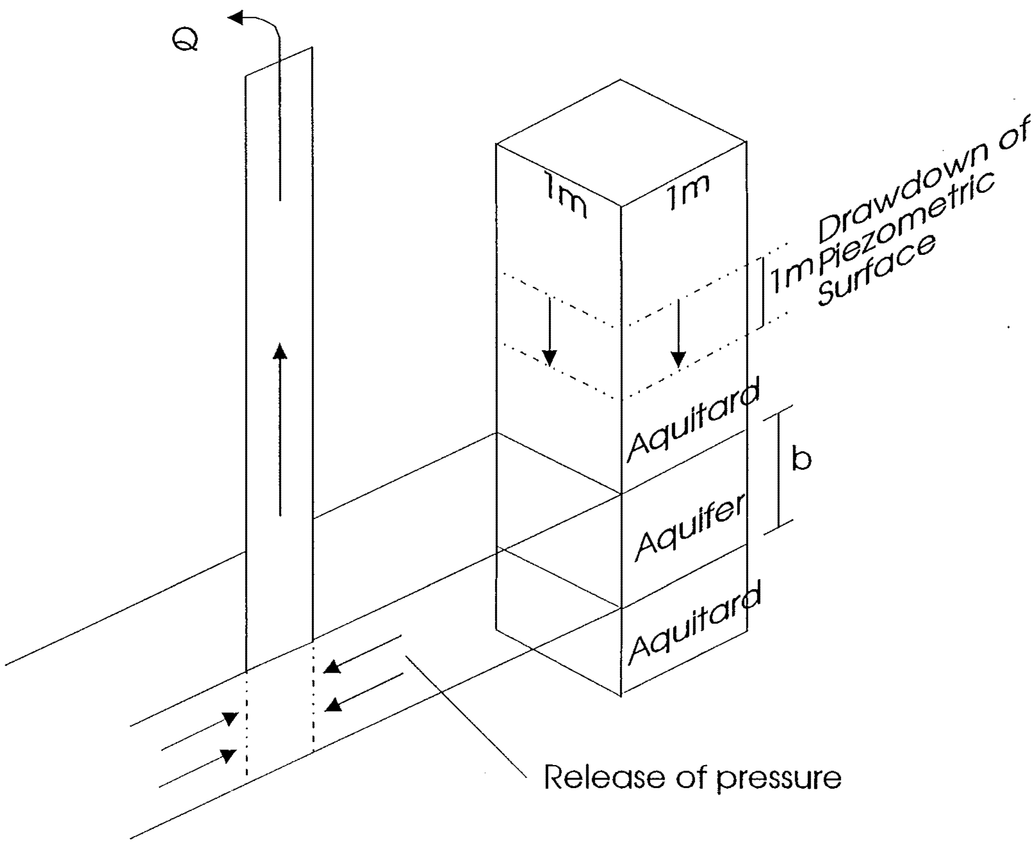


FIGURE 4.5. Confined Aquifer Storativity.

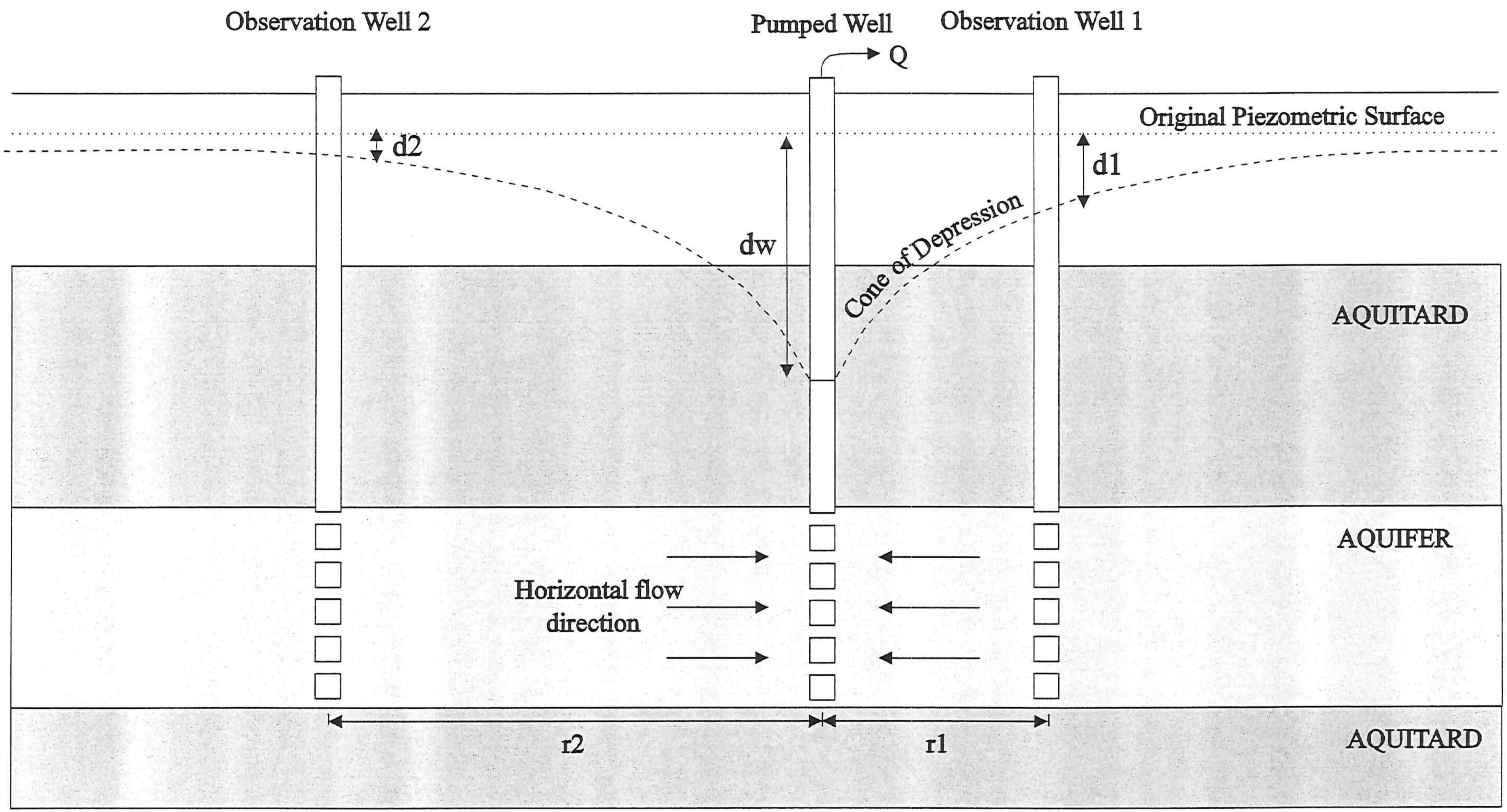


Figure 4.6. Pump testing layout for a confined aquifer.

Q = flow rate; dw = drawdown in pumped well;
d1 & 2 = drawdown in observation wells
and r1 & 2 = radius of observation wells from pumped well.

2. The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.

3. The pumped well fully penetrates the aquifer thickness, thus receiving water only via a horizontal flow path.

4. Before the initiation of pumping the piezometric surface is horizontal or near horizontal over the area to be influenced by the pumping test.

5. The aquifer is pumped at a constant rate of discharge.

These are only general assumptions, for more complex tests and forms of analysis further assumptions must be introduced. In actual pumping test situations, however, these assumptions are infrequently satisfied and it should be recognised that values for aquifer characteristics obtained through pump test analysis are not exact. It should also be noted that if a model fits the pump test data, this does not prove that the aquifer fits the assumptions on which the model is based.

Available aquifer charateristics obtained from pump test analyses for the Kaikoura Plains are presented in Table 4.1 below. All of the pumping tests undertaken to date have been carried out on Aquifer 2. The values for aquifer transmissivity shown indicate a general decrease in transmissivity within Aquifer 2 towards the coast. This could be due to a decrease in average grainsize of aquifer materials with distance from there point of origin.

Well Number	Grid Reference	T (m^3/min/m)	S
O31/115*	661 699	0.043 to 0.21	7.4×10^{-4}
O31/156	657 684	0.0715	3.81×10^{-5}
O31/184	659 707	0.079	-
O31/200	640 709	0.626	-
O31/204*	637 717	2.47	2.49×10^{-4}

* indicates values obtained in this study.

Table 4.1. Kaikoura Plains Aquifer Characteristics.

4.4 Groundwater Recharge

4.4.1 Recharge Sources

On the Kaikoura Plains four main sources of groundwater recharge have been identified, as follows:

1. Recharge from Kowhai River leakage entering the permanent groundwater system in the upper to middle region of the Kaikoura Plains. River leakage involves river water from either surface flow or underflow infiltrating to permanent groundwater.

2. Recharge from Mt. Fyffe streams leakage to the groundwater system in the upper plains area. As the Mt. Fyffe streams exit from their gorges, where bedrock inhibits the downwards seepage of surface flow, they generally lose the bulk of their surface flow into their permeable fan deposits before they flow only a few hundred metres onto the Plains surface.

3. Direct recharge from rainfall infiltration on the Plains Surface. Rainfall infiltration is a factor of total rainfall, evaporation rates, soil moisture content and soil moisture holding capacity.

4. Recharge from inter-aquifer leakage. The generalised flow patterns for a coastal aquifer system such as the Kaikoura Plains involves downwards flow in the recharge (landwards) area of the aquifers, and upwards flow in the coastal end of the aquifer system. However inter-aquifer leakage is unable to be quantified, and therefore will not be discussed.

4.4.2 River Recharge.

Evidence supporting river recharge comes from two sources, stream gauging data and isotopic data. Stream gauging data gives quantitative evidence in the form of losses, or gains, in surface-water flow rates, while isotopic data gives more qualitative evidence by indicating possible recharge sources for groundwater. The Kahutara and Hapuku Rivers have been ignored in terms of recharge sources for Kaikoura Plains groundwater as they only interact with localised groundwater systems separate from that of the central Kaikoura Plains. The Kahutara River is isolated from the Kaikoura Plains groundwater system by the Kahutara Hills, and the Hapuku River is isolated by both its deep entrenchment within its fan and also by a baserock high as indicated by the outcropping Kincaid Hills.

Stream Gauging

Three sets of stream gaugings have been carried out in the Kaikoura area, two in 1980 and 1981 by the Marlborough Catchment Board and the other in February, 1995 by the writer. Gauging sites are shown in Figure 4.7 and stream gauging data is presented in Appendix VI. Gaugings were undertaken using a Pigmy type flow meter, and gauging data (this study) was processed using the Canterbury Regional Councils stream gauging software.

Gains and losses to surface flow were calculated as the difference in flow rates between gauging sites, with gains or losses being attributed to interaction with the groundwater system. From the stream gauging data (this study) presented in Figure 4.8 it can be seen that the Kowhai River is the major source of groundwater recharge followed by the Waimangarara River and Luke, Floodgate and Middle Creeks respectively. Stream gauging data shows that the Kowhai River surface flow declines from the gorge to Middle Ford, by 478 l/s. It is uncertain however whether this loss is due entirely to leakage to the groundwater system or if a degree of underflow is involved. Below Middle Ford the Kowhai regains 136 l/s of its surface flow, here again it is uncertain as to how much of this gain can be allocated to groundwater discharge and how much to underflow re-surfacing. A comparison of gauging data from this study with those undertaken previously in the Kaikoura area indicate a high degree of variability (Table 4.2) and illustrates the need for extended records to enable values which most accurately represent the true interaction between groundwater and surface flow to be obtained.

Change in surface flow rates	**Maximum (l/s)**	**Minimum (l/s)**
Loss to Kowhai River flow	834	478
Gain to Kowhai River flow	136	91
Loss to Mt. Fyffe stream	436	186
Gain to streams on lower Plains	1026	720

Table 4.2. Variation of stream gauging data.

From the gauging data it can be seen that during times of low flow the groundwater system gains 679 l/s from river leakage and 1143 l/s during moderate to high flow.

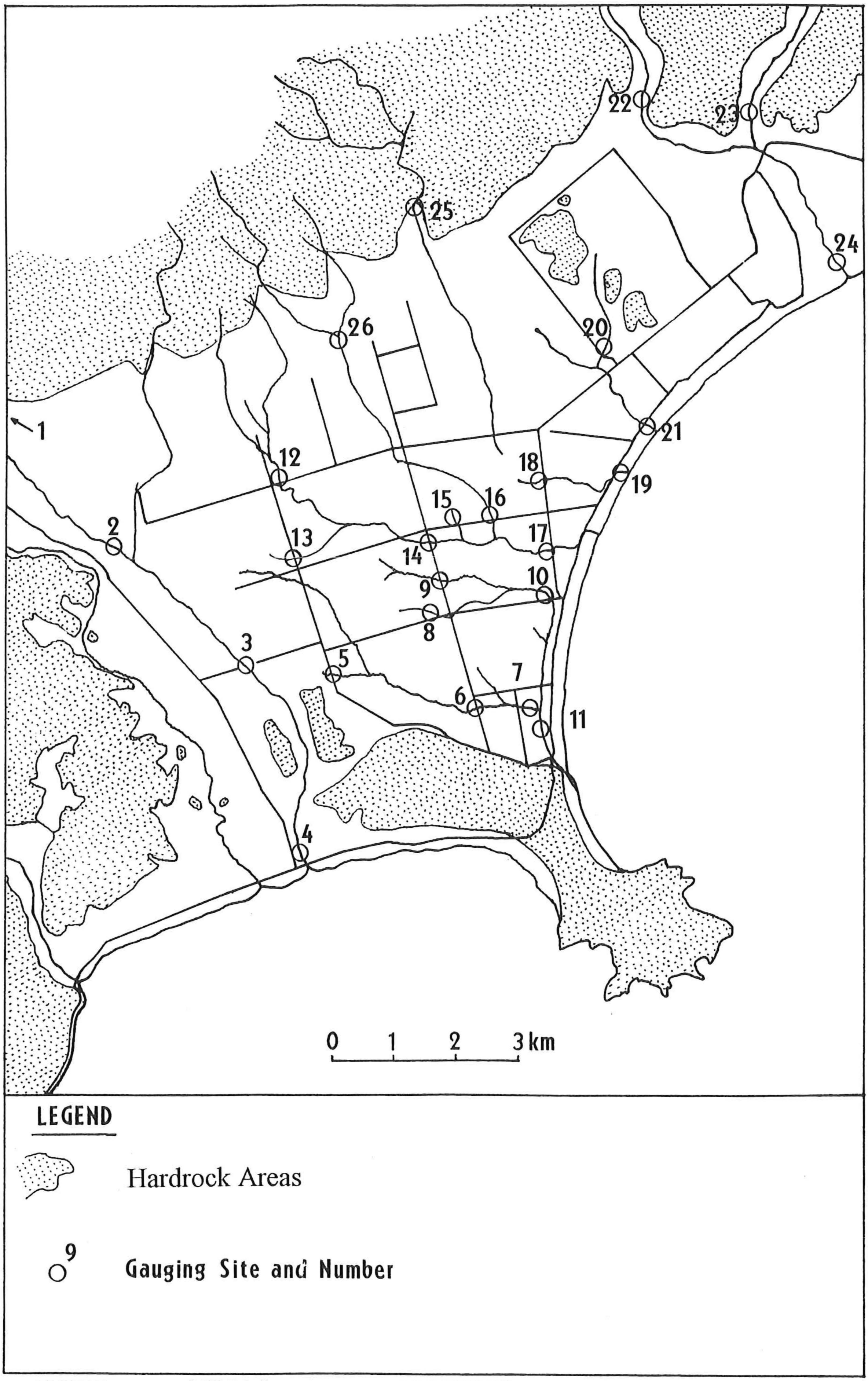


FIGURE 4.7. STREAM GAUGING LOCATIONS.

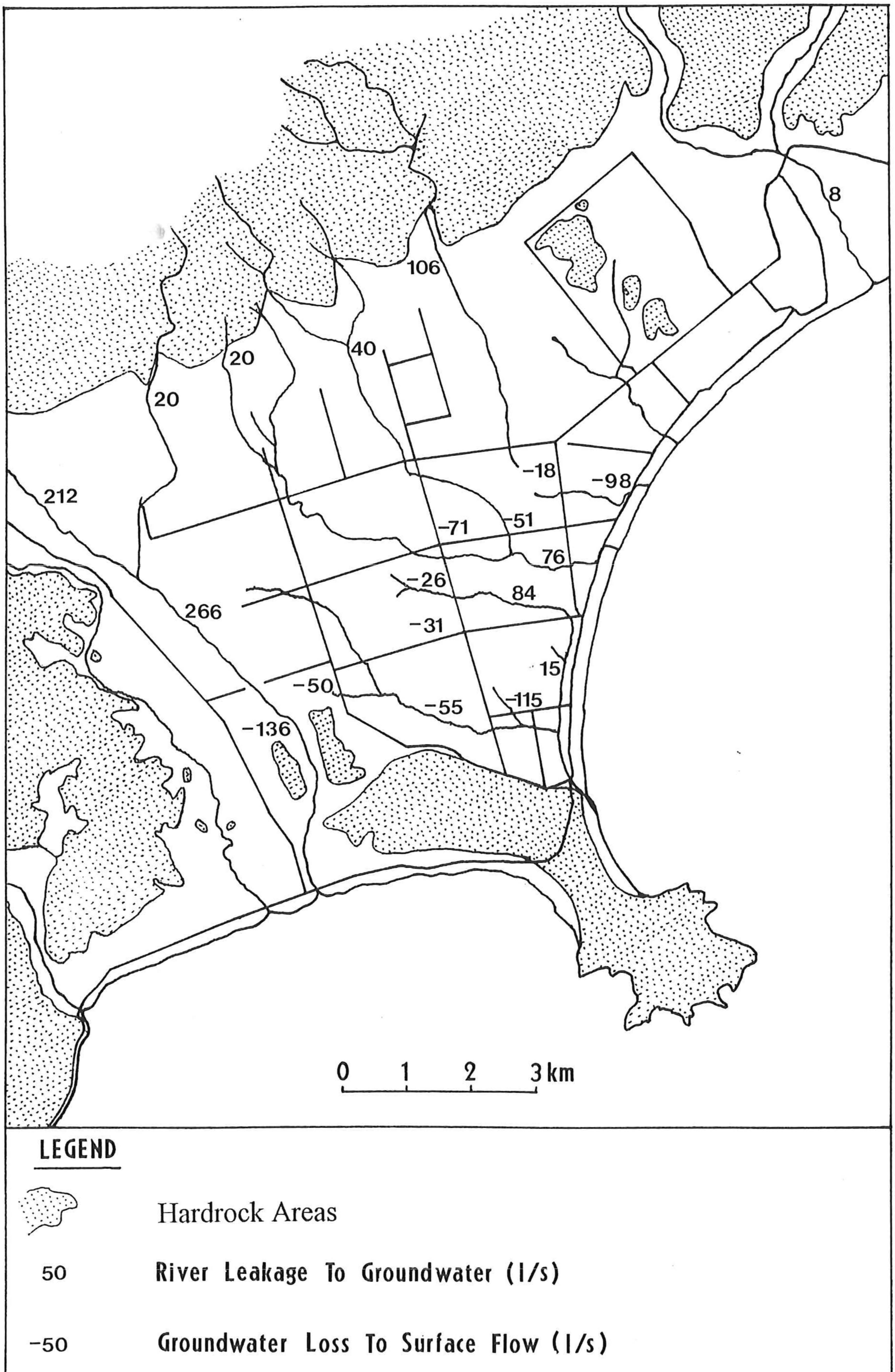


FIGURE 4.8. Gains and Losses to Groundwater from Streamgauging (February, 1995).

Isotopic Evidence

Isotopic analyses were carried out by Brown and Taylor (1974), and the isotopic results relevant to the present study are given in Appendix VII. Deuterium and oxygen 18 values for water table wells (Aquifer 1) ranged from -5.9 to -8.5, with a value of -9.4 for the flowing artesian aquifer and -8.9 for the non-flowing artesian aquifer (both Aquifer 2). Brown and Taylor (1974) also used the isotopic analyses to identify recharge paths of the separate aquifers. By examining tritium, deuterium and oxygen 18 isotopic data from both surface and groundwater sources in the Kaikoura area, the following flow paths for groundwater in the aquifers was established (after Brown and Taylor, 1974):

1. Aquifer 1 is recharged by infiltration of the water of the Mt. Fyffe streams into their fan surfaces, the Kowhai River also contributes to Aquifer 1 immediately adjacent to the river. Lower on the plains the Aquifer 1 is influenced by local precipitation. Water of the Aquifer 1 is very young and derived from local precipitation.

2. Aquifer 2 receives the bulk of its water from the Kowhai River, however it also receives a small component of water from the drainage of Mt. Fyffe in the upper plains region. Tritium values indicate that the water of Aquifer 2 varies in age and is possibly up to several decades old, while other values for Aquifer 2 indicate relatively fast recharge. There is no isotopic data available for Aquifer 3.

4.4.3 Rainfall Recharge

The amount of rainfall that infiltrates to the permanent water table as a proportion of total rainfall is dependent on a number of factors (NCCB, 1983), these being; 1. the available water holding capacity of the soil (AWC), 2. soil moisture prior to rainfall occurring, 3. the intensity and duration of the rainfall and 4. evaporation and transpiration rates. Therefore, a general equation for determining ground water recharge from rainfall is:

$$\text{recharge} = (\text{rainfall} - \text{evapotranspiration} - [\text{AWC} - \text{soil moisture}]) \times \text{area}$$

Values for rainfall and evapotranspiration determine the amount of rainfall available to contribute to groundwater recharge. The values for available water holding capacity and existing moisture content of the soil then determine the portion of this available rainfall which is available to infiltrate to the permanent watertable. A value for rainfall recharge to the Kaikoura groundwater system has been calculated as 1775 l/s (see section 6.2.2).

The main source for nitrate nitrogen in groundwater is from the infiltration of rain and irrigation water from pastoral and arable land. Thus shallow or unconfined aquifers with a high component of rainfall recharge will tend have to considerably higher levels of nitrate nitrogen than confined aquifers with only little or no rainfall recharge component. The nitrate nitrogen levels obtained from the sampling program (Figure 4.9) are consistent with Brown and Taylor's (1974) isotopic analysis. Aquifer 1 had generally high nitrate nitrogen levels indicating recharge mostly from local rainfall except for localised river input. Nitrate nitrogen levels for Aquifer 2 show two main trends: one with slightly elevated levels indicating mostly river recharge with some mixing of local rainfall recharge high in nitrate nitrogen in the upper plains area, while the other had low nitrate nitrogen levels indicating almost entirely river recharge.

Isotopic data (Brown and Taylor, 1974) as discussed in the preceding section and elevated nitrate levels (this study) as discussed above, indicate that rainfall is a dominant source of recharge for Aquifer 1 and also for areas of Aquifer 2 in the upper Plains area. Water level fluctuations with rainfall are shown in Figure 4.10. These fluctuations show a greater response to rainfall over the winter months than over the summer months. This is because during winter, rates of evapotranspiration are much less than during summer and soil moisture levels are usually very close to the soil moisture holding capacity, this means that most winter rainfall recharges groundwater. During the summer months, when soil moisture deficits and evapotranspiration rates are much higher, there is minimal groundwater recharge from rainfall as most of the rainfall which is not lost to evapotranspiration is retained as interstitial water within the soil. Water level response to rainfall in confined aquifers may be a response to increased pressure in the aquifer due to loading of overlying aquifers and aquitards by rainfall infiltration, rather than actual rainfall recharge to the confined aquifer. Alternatively, the response may be due to increased pressure in the aquifer caused by rainfall recharge in an unconfined portion of the aquifer. Figure 4.10 shows that while Aquifer 2 is responding to the rainfall events, the response is not as large as that of Aquifer 1.

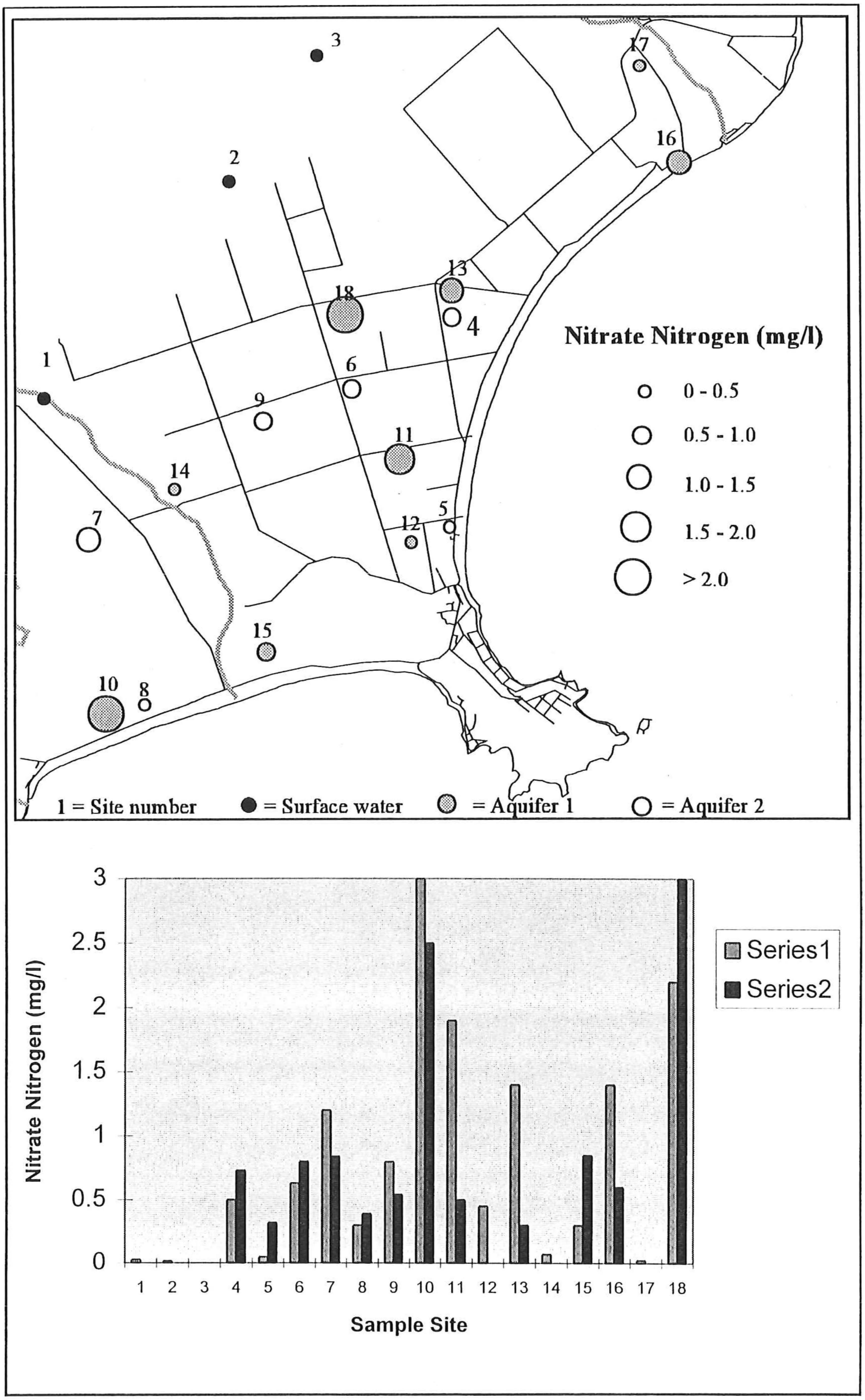


Figure 4.9. Nitrate Nitrogen values and spatial variation.

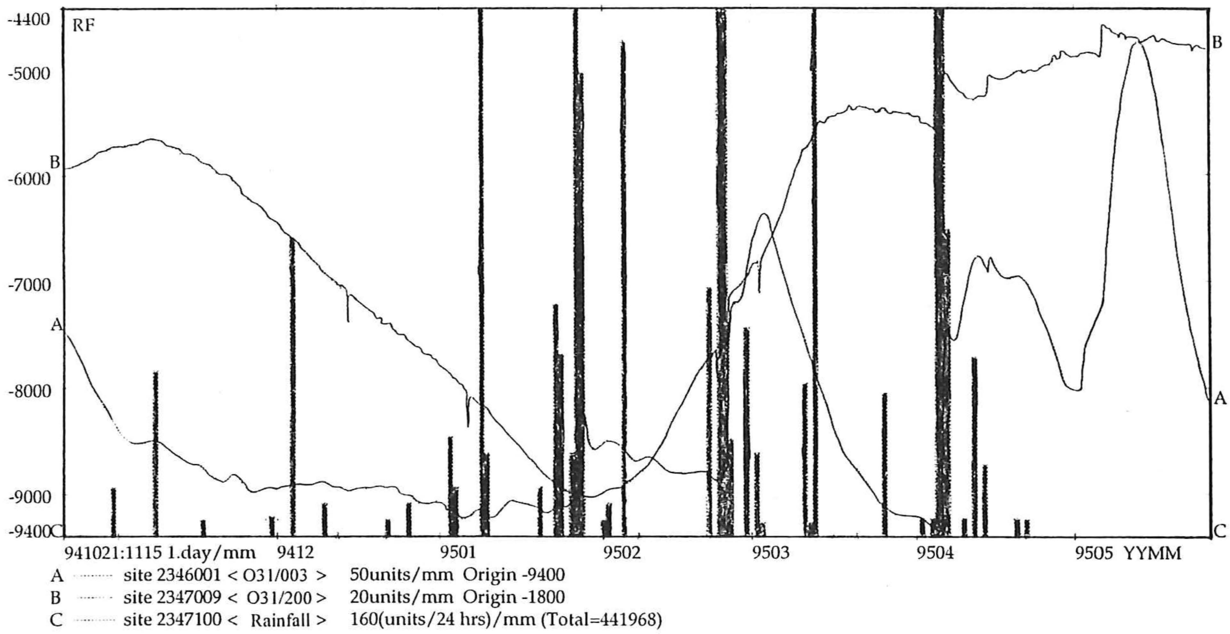


Figure 4.10. Groundwater response to rainfall.

4.5 Groundwater Discharge

4.5.1 Spring Flow

The majority of streams and drains on the plains below Schoolhouse Road are spring fed, with spring influence occurring higher on the Plains after extended periods of wet weather. The term spring is used loosely here, the majority of "springs" on the Kaikoura Plain consist of an ill defined area of seepage rather than a localised vent through which the spring flows. The few localised spring vents which do exist have mostly been made by digging a casing, such as a PVC or concrete pipe, into an area of seepage so as to provide the spring water with an easier passage to the ground surface. Stream gauging data (Appendix VI) gives an estimated discharge of groundwater via springs and seepages to streams and drains as 811 l/s during low flow and 1162 l/s during moderate to high flow. These values are the result of only three sets of stream gaugings and therefore only represent guideline values. For more accurate values records of several years of summer and winter gaugings would be required.

4.5.2 Through Flow

Through flow is the volume of water left flowing through the aquifer when all other input and output factors have been taken into account and ultimately is the volume of water which discharges out to sea. Through flow can be estimated by summing all other known aquifer inputs and outputs when the aquifer is in a state of equilibrium, that is, when total aquifers inputs equal total aquifer outputs. Through flow for the Kaikoura aquifer system has been estimated as 1635 l/s under summer conditions and 1865 l/s under winter conditions.

4.6 Piezometric Survey

4.6.1 Introduction

Piezometric contours are lines on a map which join points of equal potential energy, or equipotential. In other words when a well taps an aquifer the water will rise in the well casing to a particular elevation which is known as the piezometric level. Where there are a number of wells which penetrate the same aquifer the elevation of the water or the piezometric levels of these wells can be contoured creating a piezometric contour map or piezometric surface. A piezometric surface gives an indication of the general groundwater flow direction (down gradient, perpendicular to lines of equipotential) and also the hydraulic gradient (taken from the slope of the piezometric surface). It is also possible to calculate regional flow rates and aquifer storage by combining the hydraulic gradient with hydraulic conductivity, and either specific yield (unconfined aquifer) or storativity (confined aquifer).

Wells used in the piezometric surveys were obtained by a door to door survey of the Kaikoura District. At each property it was first ascertained whether or not any wells were present and the located wells were then measured for total depth, diameter and depth to water. These wells were then matched with those on the Canterbury Regional Councils existing database and those not already on the database were given appropriate well identification numbers and added to it. Of the 260 or so wells on the CRC's wells data base in the Kaikoura area, only 89 were able to be used in the piezometric survey. This is due to a number of reasons, firstly a large number of older wells have been filled in, covered over or otherwise lost; secondly, an even larger number of the wells documented in the wells database were foundation test bores for buildings, bridges and an old floodplain management proposal to divert the Mt. Fyffe streams; and thirdly a number of wells were unable to be used in the piezometric survey because they had been sealed so that access could not be obtained with a depth to water probe.

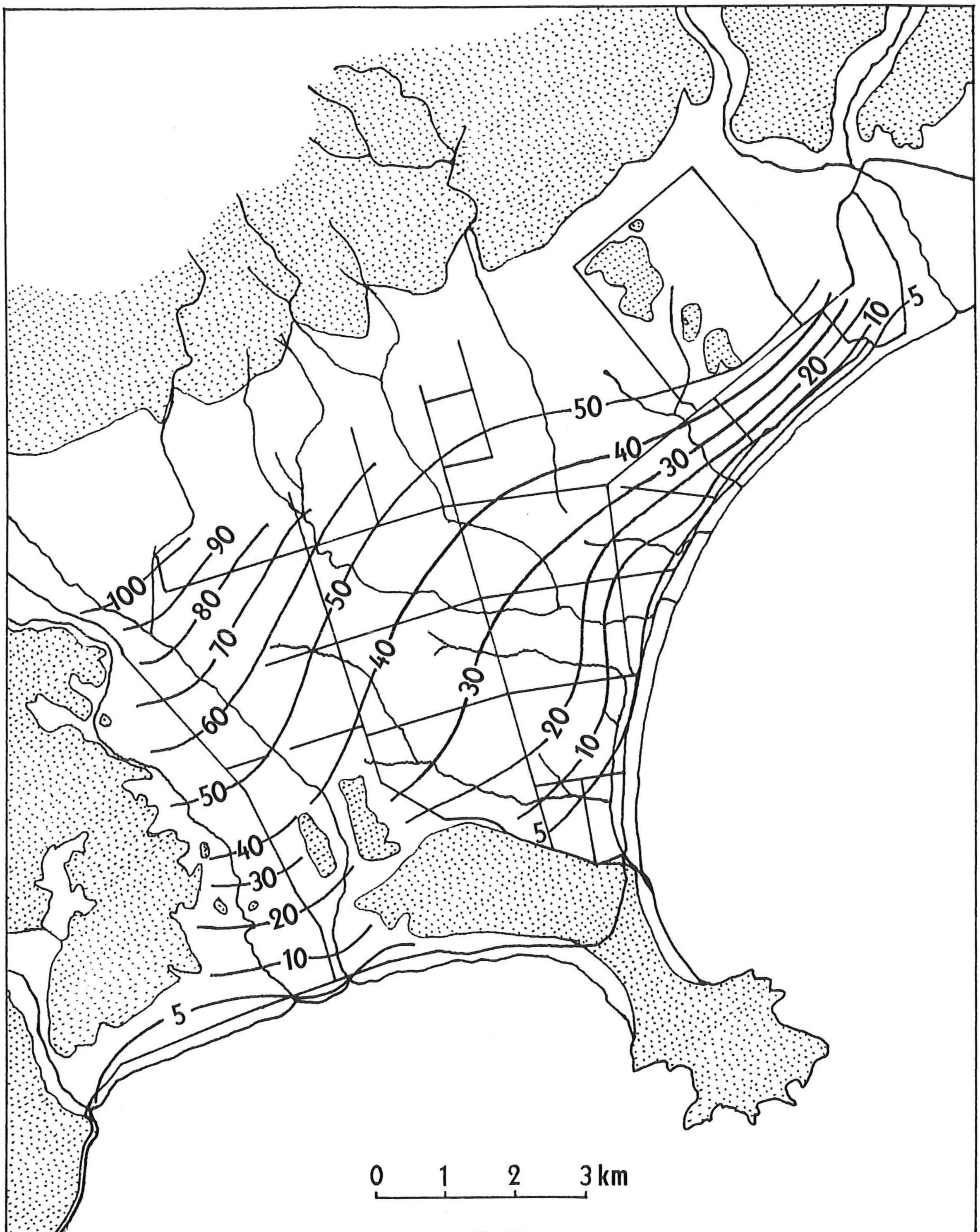
A low-level summer piezometric survey was conducted by the writer over the two days of January 31 and February 1, 1995 and a high level winter piezometric survey was conducted over 28 and 29 June, 1995. The data obtained in these piezometric surveys is presented in Appendix VIII. No previous piezometric survey data was available for the Kaikoura area.

4.6.2 Aquifer 1

Figure 4.11 shows the summer and winter piezometric surfaces for Aquifer 1 as determined in this study. Aquifer 1 displays a general south - southeast flow direction in both the winter and summer surveys, with an average gradient of 12m/km. Both surveys show a down gradient curvature in the vicinity of the Kowhai River suggesting localised recharge to groundwater. This type of bending of the contour lines generally indicates aquifer recharge, a down-gradient curvature indicates aquifer input while an up-gradient curvature indicates aquifer output. Other than the difference in water levels, contour patterns are much the same between both winter and summer surveys. However in the summer survey there is a distinct flattening of the piezometric surface in the central plains area with a down gradient curvature of the contour lines between Hawthorne and Mill Roads which could be due to upwards leakage from Aquifer 2 to Aquifer 1. The steep hydraulic gradient indicated by the close spacing of contour lines on the Hapuku River fan is due to the lowering of the piezometric surface via springs along the base of the truncated fan.

4.6.3 Aquifer 2

Aquifer 2 also displays a general south - southeast flow direction in both surveys, with an average gradient of 13m/km (Figure 4.12). The flow pattern of Aquifer 2 is more complex than that of Aquifer 1 and shows a prominent recharge event occurring in the vicinity of Kowhai Ford, this recharge is more pronounced in the winter survey. A down gradient curvature in the vicinity of the Waimangarara River suggests the influence of river recharge in this area with a more pronounced input during the winter survey. No piezometric data is available for Aquifer 3.



LEGEND

Hardrock Areas

90 Piezometric Contours (meters above M.S.L.)

Figure 4.11a. Aquifer 1 Piezometric contours (February, 1995).

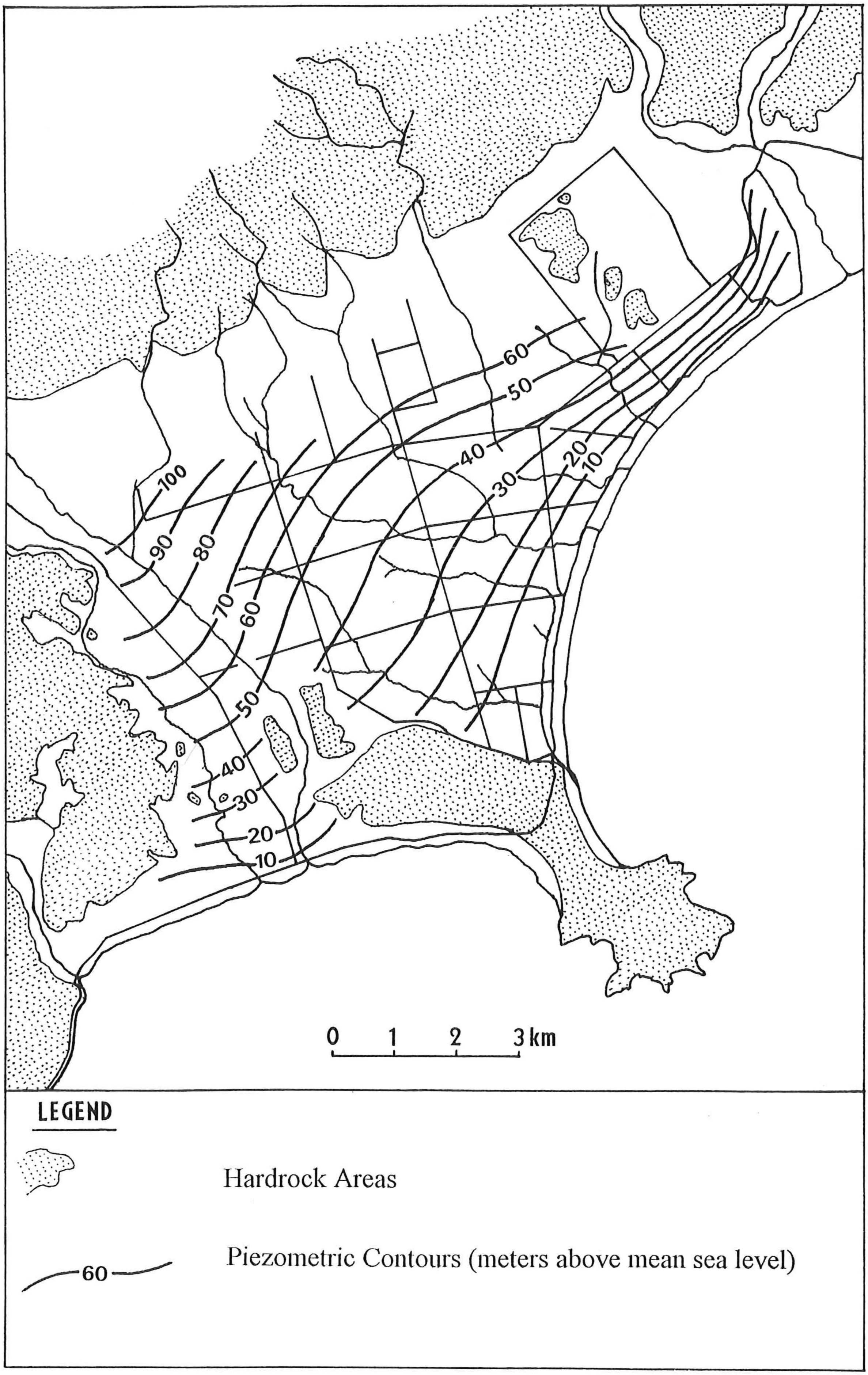


Figure 4.11b. Aquifer 1 Piezometric contours (June, 1995).

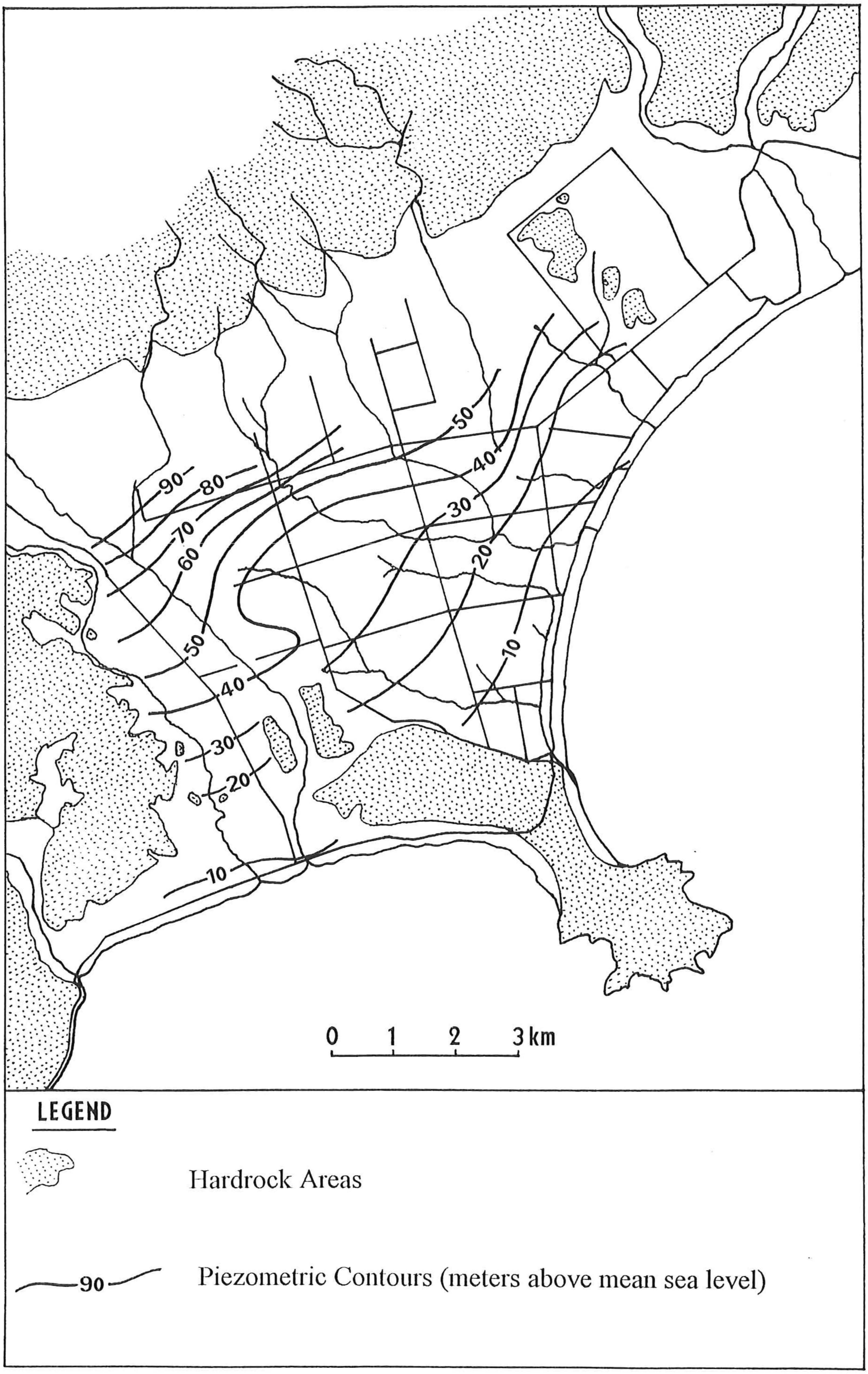


Figure 4.12a. Aquifer 2 Piezometric contours (February, 1995).

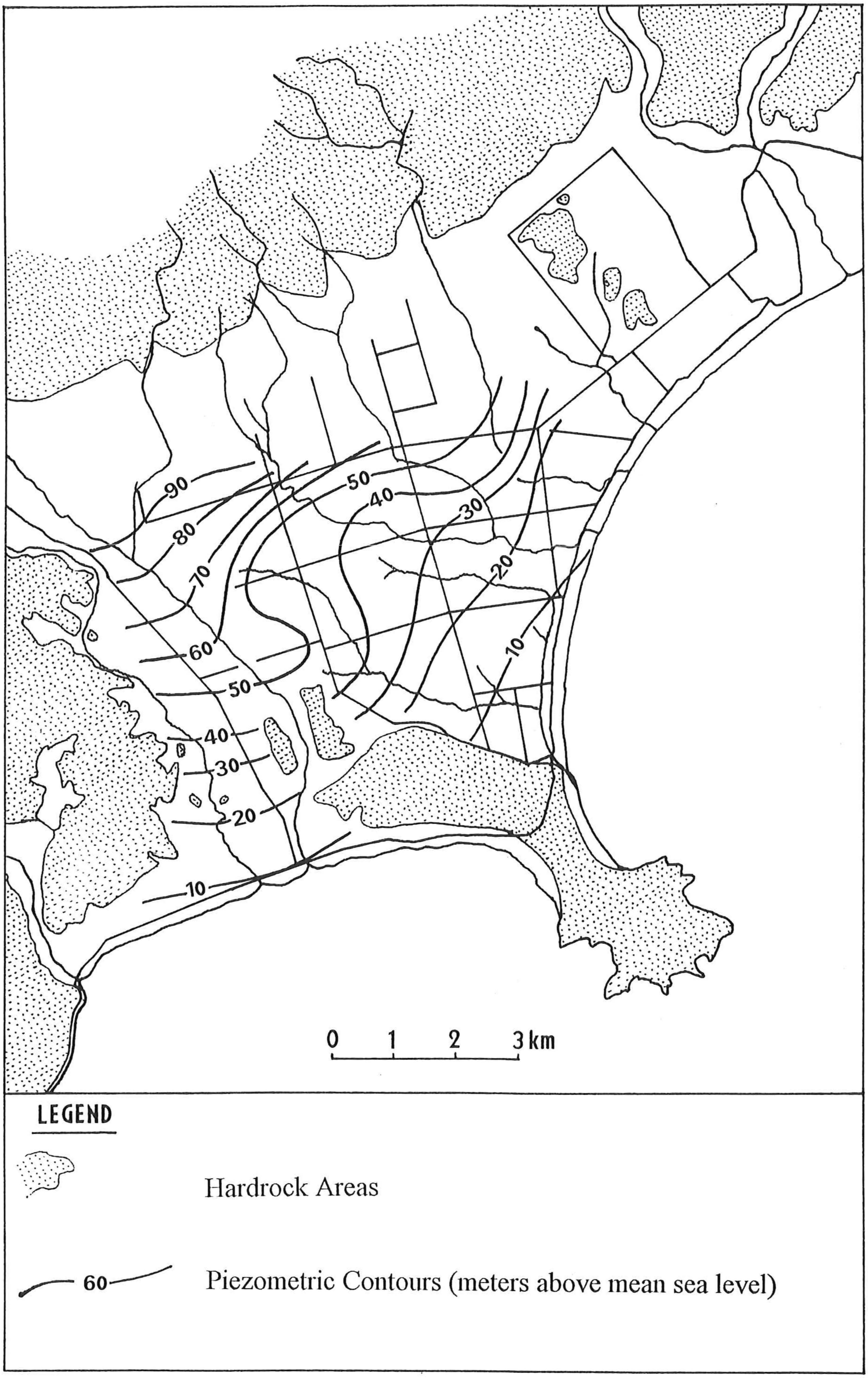


Figure 4.12b. Aquifer 2 Piezometric contours (June, 1995).

4.7 Groundwater Fluctuations

4.7.1 Observation Wells

Groundwater levels of the Kaikoura Plains were monitored using a network of 25 observation wells, the locations of which are shown in Figure 4.13. Of these 25 observation wells the water levels in 17 wells were measured manually approximately every fortnight, while the other eight wells were fitted with automatic water level recorders with readings being taken either every 15 minutes or every hour depending on the type of recorder. Well hydrographs of the observation wells are presented in Appendix IX. From studying these records fluctuations in groundwater levels can be observed over time and correlated with external events.

Temporal fluctuations in groundwater levels may be observed on three different levels:

1. long-term fluctuations, these may be observed over a number of years;

2. seasonal fluctuations which are observed on a annual basis; and

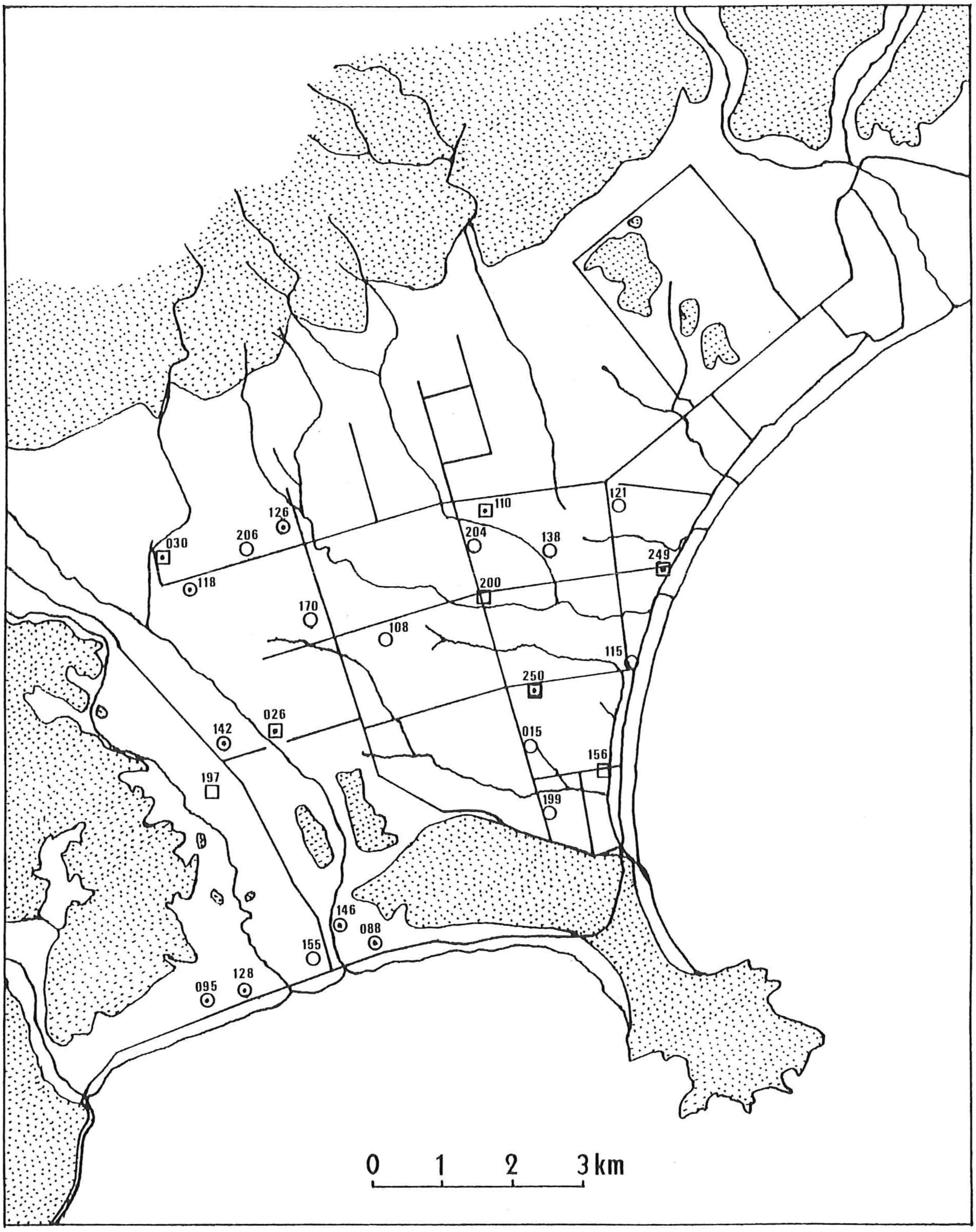
3. short-term fluctuations, which may last from only a few minutes to a few weeks.

4.7.2 Long-term Groundwater Fluctuations.

Long term lowering of regional groundwater levels represents a depletion of aquifer storage. This may arise from groundwater demands being consistently greater than groundwater recharge, thus resulting in a lowering of average groundwater levels, or otherwise it may represent a decrease in groundwater recharge. There has been no obvious increase or decrease in general groundwater levels of the Kaikoura Plains.

4.7.3 Seasonal Fluctuations.

Seasonal fluctuations in groundwater levels are a response to fluctuations in groundwater supply and demand. Over the summer months reduced input into the groundwater system resulting from increased evaporation and decreased precipitation, combined with increased abstraction for irrigation creates a summer low. Over winter and spring, however, lower evaporation combined with increased rainfall and snow melt input into the groundwater system creates a winter high.



□ Automatic Site ⊡,⊙ Aquifer 1

○ Manual Site □,○ Aquifer 2

156 Well Identification Number (031/)

Figure 4.13. Observation Well Locations.

Seasonal groundwater fluctuations are illustrated in Figure 4.14, which shows a general trend of summer lows and winter highs, however these seasonal fluctuations can be disrupted by unusually dry winters or summer storm events.

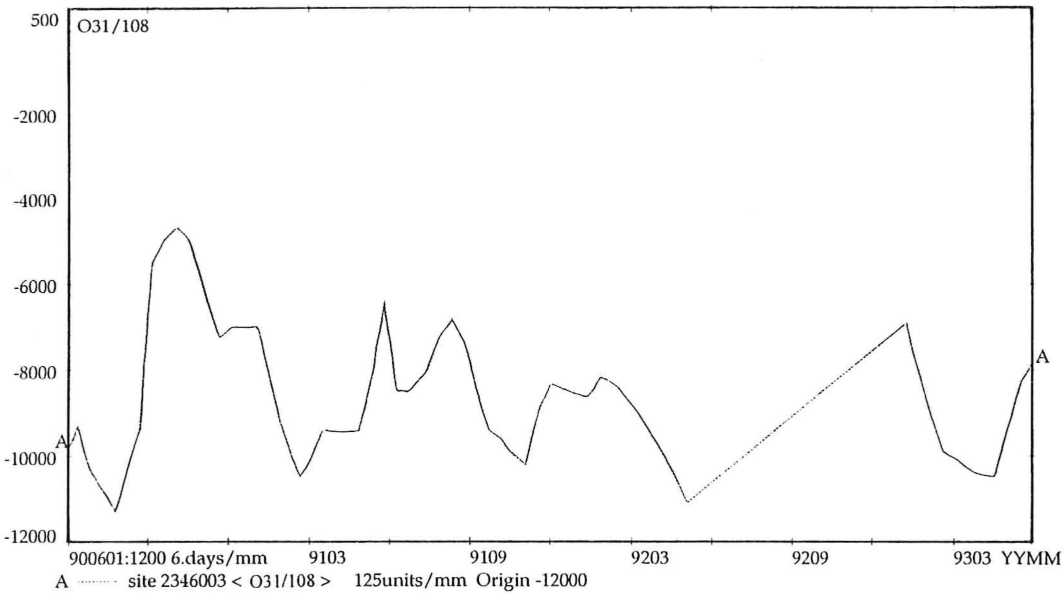


Figure 4.14. Seasonal Fluctuations of groundwater levels of well O31/030.

4.7.4 Short-term Groundwater Fluctuations.

Short term fluctuations, which may be ether localised or widespread, can arise as a direct response to physical inputs into, or outputs from a groundwater system, or they may be due to pressure changes within an aquifer system. Pressure changes within an aquifer may result from; the loading of overlying sediments, tidal fluctuations or changes in atmospheric pressure.

Input Events.

One of the most obvious and common aquifer inputs is that of natural recharge to the aquifer from either river leakage or rainfall infiltration. The effect of recharge events is usually regional rather than a localised effect. Groundwater response times to rainfall events on the Kaikoura Plains vary from an almost immediate response in Aquifer 1 with a lag time of up to two weeks for Aquifer 2 near the coast.

Output Events.

Output events resulting in short-term groundwater fluctuations are generally related to artificial abstraction or pumping. The effect of abstraction from a well is to create a localised cone of depression in which piezometric levels are lowered (refer Figure 4.6), the extent of which is reliant on the aquifers hydraulic properties and the duration and volume of abstraction. Both the pumped well and those in close vicinity will experience a drawdown and recovery effect after initiation and cessation of pumping, and the effect will be lessened the further away a well is from the pumped well. The effect of periodic abstraction from a well is obvious on the hydrograph of well O31/200, shown in Figure 4.15, which shows the influence of periodic abstraction from a well approximately 600 metres away.

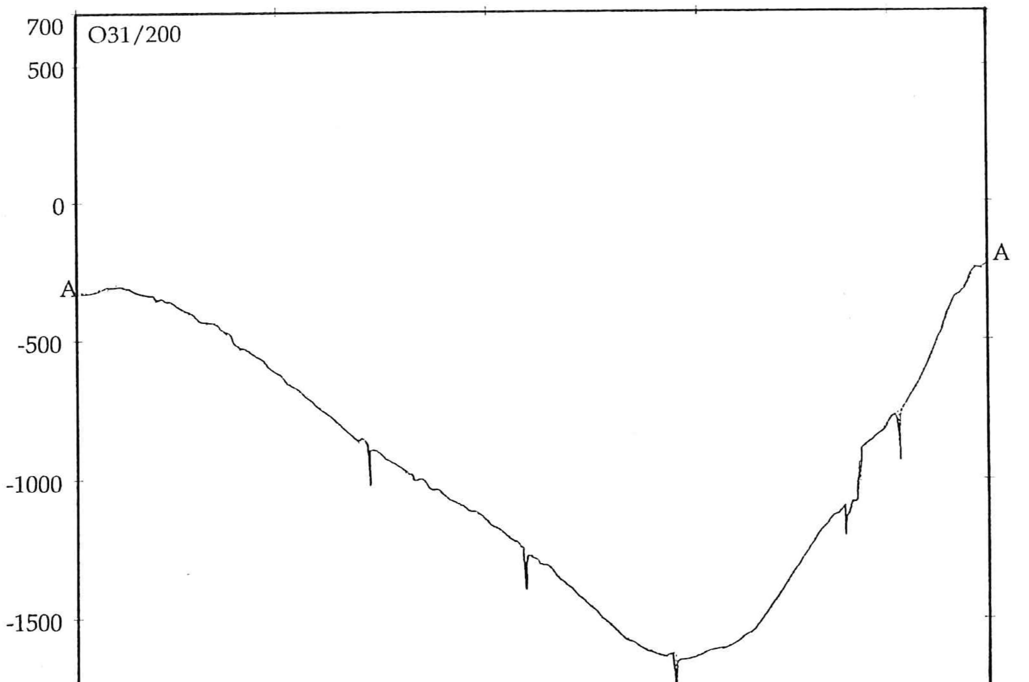


Figure 4.15. This well hydrograph shows the effect of periodic abstraction from a well located over 600 metres away. The drawdown is represented by the spikes in the curve.

Tidal effects.

Fluctuations in groundwater levels due to the rise and fall of tidal fluctuations can occur if aquifers are hydraulically connected to the sea, thus increasing tidal levels represent an increase in the hydraulic head of the aquifer. Tidal effects are diminished with increasing distance from the coast. Tidal fluctuations of about 20mm have been observed in well O31/003 as shown in Figure 4.16a and of about 10mm in well O31/156. Well O31/156 is 400 m from the coast while well O31/003 is 200 m from the coast, the peak of well O31/003 was lagging behind the high tide peak by 105 minutes In both cases the tidal range was approximately 1.5 meters.

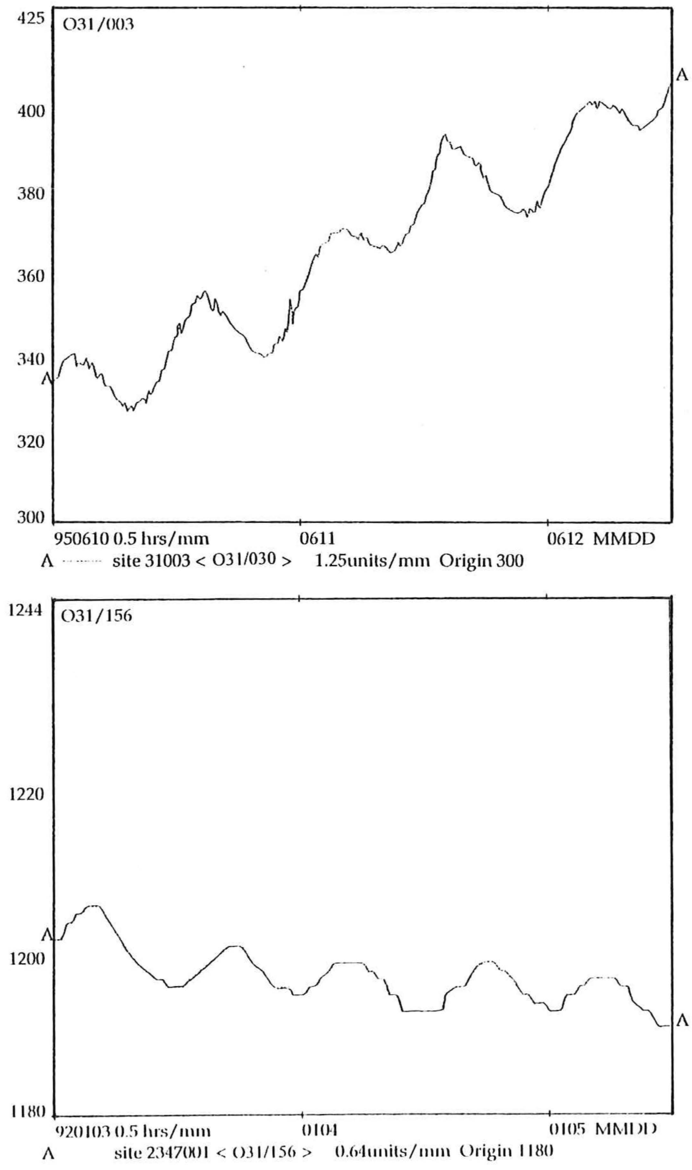


Figure 4.16 Tidal influence on the groundwater fluctuations of wells O31/003 and O31/156.

4.7.5 Groundwater Monitoring Network

From studying well hydrographs (Appendix IX) of the current observation wells (Figure 4.13) it can be seen that groups of wells show similar patterns of groundwater fluctuations. Adequate monitoring of the Kaikoura groundwater system can be maintained while reducing the number of observation wells in service, this is especially applicable to the manual observation wells. Table 4.3 below shows both manual and automated observation wells that the writer believes are sufficient for monitoring the groundwater levels of the Kaikoura Plains.

AUTOMATIC RECORDER SITES

Well Number	Grid Reference (NZMS 260, Sheet O31)	Aquifer
O31/026	613 690	1
O31/030	591 717	1
O31/156	657 684	2
O31/197	602 679	2
O31/200	640 709	2
O31/249	663 713	1
O31/250	645 696	1

MANUALLY MONITORED SITES

Well Number	Grid Reference (NZMS 260, Sheet O31)	Aquifer
O31/015	646 687	2
O31/088	626 659	1
O31/095	600 651	1
O31/108	624 700	2
O31/115	661 699	2
O31/126	609 718	1
O31/142	601 686	1
O31/146	620 664	1
O31/155	616 657	2
O31/170	612 692	2
O31/199	648 679	2
O31/204	637 717	2
O31/206	605 714	2

Table 4.3. Revised groundwater monitoring network.

Of the automatic recorder sites, the only change that the writer feels needs to be made is the removal of the pressure transducer and data logger from well O31/110 located in Aquifer 1 near the toe of the Waimangarara River fan. This well dries up seasonally and so does not provide a full record of groundwater levels for that locality. Manual records should be maintained for well O31/110 for comparison with the near by well O31/204, which is located in a semi-confined area of Aquifer 2.

The manual monitoring wells O31/118, O31/121, O31/128 and O31/138 are surplus to requirements and should not be continued with. Well O31/138 is located in Aquifer 2 below the toe of the Waimangarara River, and often has an artesian head which cannot be accurately measured, as the well casing is uncapped. Because accurate measurements can only be made when the piezometric level is below groundsurface this well does not provide a full record of the groundwater fluctuations of Aquifer 2 in this locality. However, the nearby manually measured well O31/204 and automatically measured well O31/200, provide sufficient data on Aquifer 2 groundwater fluctuations in this area. Similarly, well O31/121, also located in Aquifer 2, has an uncapped casing and has a positive artesian head for a large part of the year, and therefore does not provide any quantitative data on water level fluctuations. Well O31/118 is located in Aquifer 1 near the western end of Postmans Road, and dries up seasonally. The groundwater fluctuations in Aquifer 1 in this area are measured by the automatically monitored well O31/030, therefore well O31/118 is not required. The manually measured well O31/128, located in Aquifer 1, near State Highway 1, west of the Kowhai River, is used for irrigation purposes consistently throughout the summer months and so does not provide accurate data on groundwater fluctuations over the summer months, the near by manually measured well O31/095 does however, provide the required information on Aquifer 1 groundwater fluctuations in this vicinity.

4.8 Water Balance

4.8.1 Introduction

The water balance of a groundwater system is the sum of the total recharge components minus the sum of the total discharge components for that system. For a groundwater system in equilibrium these recharge and discharge components are equal so that the system experiences no net gains or losses. The construction of a water balance model at best involves a great deal of estimation or educated guesswork, even when an extensive data base is available on a particular groundwater system. In the case of the Kaikoura groundwater system, data used in creating the water balance model comes largely from the results of this study and as such does not have the benefit of being averaged over several years of data collection to lessen the effects of extreme data values.

This water balance model for the Kaikoura groundwater system is based solely on natural recharge and discharge components, and does not take into account artificial groundwater abstraction or artificially induced recharge such as leakage to groundwater from irrigation. At this stage in the development of the groundwater resource, abstractions for domestic and farming purposes are small in comparison to the overall quantity of groundwater available and the amount of water recharging groundwater due to excess irrigation is for all practical purposes negligible. Therefore the resulting water balance is for a groundwater system in its natural state, without the influences of human exploitation, and gives an indication of the total groundwater resource available for utilization. The water balance components considered for this model are as follows:

1. recharge from river and stream leakage to groundwater;

2. recharge from rainfall infiltration to groundwater;

3. discharge to surface flow via springs and seepages; and

4. offshore discharge to the sea.

4.8.2 Aquifer Input Events

River and Stream Recharge

In determining the contribution of river recharge to the groundwater balance the Kahutara and Hapuku Rivers have not been considered as they are believed only to influence localised groundwater systems which do not interact with the central Kaikoura Plains groundwater system.

The amount of river leakage to groundwater has been estimated from streamgaugings as outlined earlier in section 4.4. Loss of stream flow due to factors such as evaporation or artificial abstraction have been neglected. The amount of flow lost to evaporation is not expected to be significant in comparison to total flow volumes, and to the writer's knowledge no abstractions were taking place at the time of the gaugings.

Kowhai River.

The Kowhai River is the main source of groundwater recharge to the Kaikoura groundwater system with inputs ranging from 480 l/s at times of low flow to 830 l/s at times of moderate to high flow. Groundwater input from the Kowhai River occurs between the gorge and Kowhai Ford (Figure 4.8).

As the Kowhai River bed is located within permeable gravel deposits the amount of water lost as underflow is expected to be insignificant as any leakage would infiltrate directly to permanent groundwater. If underflow is taken into account as a proportion of loss of surface flow, this value would only be canceled out later, as a proportion of the gain in flow of the Kowhai River below Kowhai Ford from groundwater input would be designated as underflow resurfacing. Ultimately, the exclusion, or not, of underflow from river leakage data for the Kowhai River has no effect on the final water balance.

The Mt. Fyffe Streams.

The Mt. Fyffe streams include: Floodgate, Luke and Middle Creeks; the Waimangarara River; and Harnetts Creek. At times of low flow these streams have a combined input to groundwater of 190 l/s; and at moderate to high flow have an input of 440 l/s. This loss of flow via subsurface leakage generally occurs almost immediately after the streams exit their gorges and flow onto the Kaikoura Plains. Only in the event of extremely high flows do the Waimangarara River and Luke Creek have surface flows as far out on to the plains as Postmans Road.

Rainfall Recharge

Estimation of the amount of rainfall recharge to an aquifer is extremely subjective and is inherently associated with large uncertainties. Values for evapotranspiration rates are unknown for the Kaikoura Region, so a value for potential evaporation has been estimated as being one half of the total rainfall. This value has been based on typical values for the Canterbury Plains (NCCB, 1983), but is reduced to take into account the effect that the hot, dry northwesterly winds have on evaporation rates on the Canterbury Plains. As northwesterly winds are not nearly as prevalent in Kaikoura as they are on the Canterbury Plains, the evaporation rate will be significantly lower. A weighted mean value for AWC has been calculated as 45 mm, taking into account the AWC of specific soils (Figure 1.4) and the area covered by them with respect to the total area of the Plains subject to rainfall infiltration. It has been assumed that excess rainfall on the portion of the Kaikoura Plains covered by surface aquitards, which is approximated by that covered by the low permeability Waimangarara and Taitapu soils and Waimakiriri silt loam, will be lost as surface runoff as rainfall infiltration is inhibited by the low permeability of the silts, and excess water is removed via streams and drains to the sea. From these values the amount of rainfall recharge to groundwater can be calculated using the following equation (after Rushton and Ward, 1979; and Scott and Thorpe, 1986):

recharge = (rainfall - potential evaporation - [AWC - soil moisture]) x area.

However, when values for AWC and soil moisture content are introduced to the above equation alongside values for total rainfall and potential evaporation, they become insignificant as they are several orders of magnitude smaller and will be ignored, thus for the present study the amount of rainfall recharging Kaikoura groundwater is estimated as one half of the total rainfall. The average annual rainfall on the Kaikoura Plains is approximately 2000 mm near the base of Mt. Fyffe, however this value is less lower down on the Plains where rainfall totaled approximately 1400 mm for the year from August, 1994, to September, 1995. Therefore, a generalised value of 1600 mm per year has been used to determine the rainfall recharge component of the water balance. This gives a rainfall recharge component of 800 mm/year over an effective area of 70 km^2, which equates to 1775 l/s input to the Kaikoura groundwater system from rainfall infiltration.

4.8.3 Aquifer Output Events

Spring Discharge

Groundwater losses to surface flow via seepage to streams and drains have been estimated from streamgaugings as discussed earlier in section 4.4?. The lower reaches of Middle Creek, Lyell Creek and Warrens Creek all have significant input from springs and seepages, as do the numerous smaller tributary streams and drains which feed into them. The Kowhai River was also found to gain an average of approximately 100 l/s in flow below Kowhai Ford.

Losses to groundwater from springflow to creeks and drains have been estimated from streamgaugings as 810 l/s during times of low flow and 1160 l/s during times of moderate to high flow.

Offshore Discharge

The offshore discharge to sea (or throughflow) is the excess of water calculated after all other recharge and discharge components have been taken into account. As the aquifers cannot extend beneath the sea indefinitely, at some stage they must end and presumably discharge at the sea bed. The value for throughflow also give an indication of the amount of water which can be abstracted from the groundwater system without disturbing the equilibrium of the system. Through flow has been estimated as 1865 l/s under winter conditions and 1635 l/s under summer conditions.

4.8.4 Water Balance and Conceptual Model

The elements of the water balance outlined above are summarised in Tables 4.4 and 4.5, and show the water balance of the Kaikoura groundwater system under both summer and winter conditions. The values for river leakage and springflow used in these water balances are those from stream gaugings undertaken in October 1983 by the Marlborough Catchment board (moderate to high flow) simulating typical winter conditions, and in January 1995 by the writer (low flow) representing typical summer conditions.

Input Event	**l/s**	**Output Event**	**l/s**
Kowhai River Leakage	830	Spring Flow	960
Mt. Fyffe Streams Leakage	220	Throughflow	1865
Rainfall Recharge	1775		
Total Inputs	**2825**	**Total Outputs**	**2825**

Table 4.4. Water balance components under winter conditions.

Input Event	l/s	Output Event	l/s
Kowhai River Leakage	480	Spring Flow	810
Mt. Fyffe Streams Leakage	190	Throughflow	1635
Rainfall Recharge	1775		
Total Inputs	**2445**	**Total Outputs**	**2445**

Table 4.5. Water balance components under summer conditions.

From the water balance components outlined above the following conceptual model has been constructed for the Kaikoura groundwater under equilibrium conditions (Figure 4.17). The values used are those of the water balance under winter conditions, as these values are likely to be less effected by the future development of the Kaikoura groundwater system than are the summer values. The water balance outlined is for the whole of the Kaikoura groundwater system as no separate budget components are available for the individual aquifers.

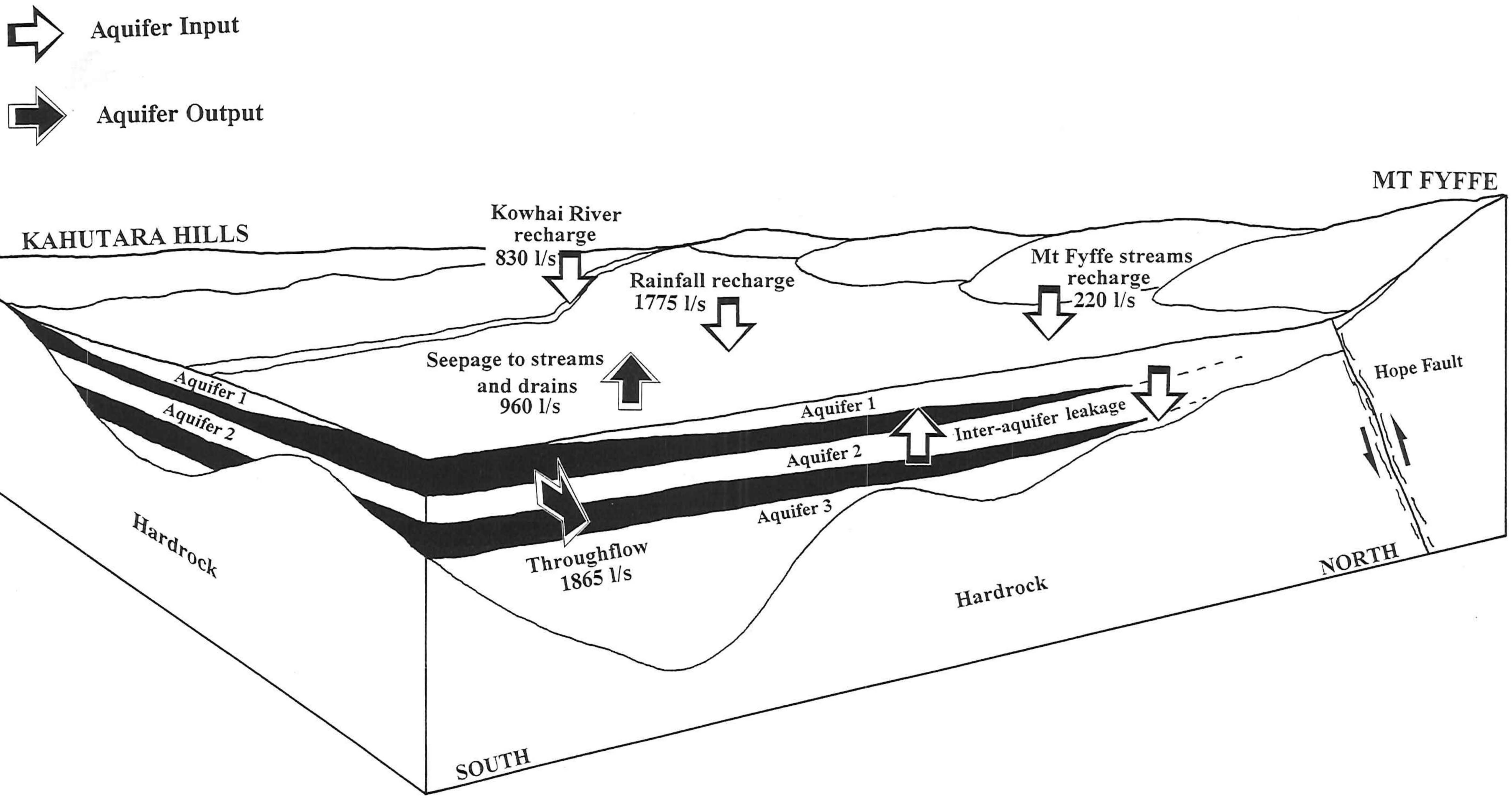


Figure 4.17. Steady state conceptual waterbalance model of the Kaikoura groundwater system

4.9 Synthesis

The Kaikoura aquifer system is comprised of at three known aquifers. Aquifer 1 is the uppermost aquifer and is largely unconfined with the exception of localised areas where a surface confining layer is present. Aquifer 1 occurs discontinuously on the upper plains surface of the Hapuku River and Mt. Fyffe streams fans and also on the lower plains in the flood channels and alluvial deposits of the Kowhai River. The age of the alluvial deposits which comprise Aquifer 1 vary from Otiran Glacial deposits to recent flood channel deposits. Aquifer 2 underlies Aquifer 1 and is confined by a layer of predominantly fine grained sediments ranging from about 2 to 10 metres in thickness. These fine grained sediments are the result of periods when the Kowhai River joined with the Kahutara River north of the Kahutara Hills during post-glacial time with only sporadic input onto the Kaikoura Plains during flood events. This resulted in the accumulation of a substantial thickness of flood silts and swamp deposits with only minor coarser grained deposits. Aquifer 2 is inferred to extend beneath the whole of the central plains area as well as west beneath the Kowhai River to the Kahutara Hills and possibly eastwards into the Hapuku River fan. Results obtained from pump testing of Aquifer 2 (this study) have indicated that the aquifer is only semi-confined in some areas and interacts hydraulically with Aquifer 1. Pump testing results also indicates that Aquifer 2 decreases in transmissivity towards the coast possibly due to a decrease in average grainsize. Aquifer 2 is inferred to consist of alluvial deposits of Otiran Glacial age. Aquifer 3 has only been identified in a small number of well logs, and is separated from Aquifer 2 by a layer of predominantly fine grained deposits similar to that separating Aquifers 1 and 2. Aquifer 3 is expected to be more limited in its areal extent than Aquifer 2, and is possibly constrained within the buried valley identified in the geophysical surveys. Aquifer 3 is, so far, unexploited and there is no data available showing any characteristics of this aquifer. It is possible that there are further aquifers beneath Aquifer 3, however, the determination of this requires the drilling of an exploratory bore.

Aquifer recharge comes predominantly from rainfall infiltration and river leakage, with the Kowhai river providing the most significant river recharge. Aquifer 1 receives river recharge on the upper plains from the Mt. Fyffe streams and locally from the Kowhai River, on the lower plains Rainfall is the main source of recharge to Aquifer 1. Aquifer 2 receives water from both the Kowhai River and the Mt. Fyffe streams as well as rainfall recharge infiltrating into the fans of the Mt. Fyffe streams. It is presumed that Aquifer 3 receives recharge almost solely from the Kowhai River, especially if it is confined within a buried valley which runs beneath the present Kowhai River Channel. Rainfall infiltration contributes 1775 l/s to the groundwater system compared with river leakage to groundwater of 1249 l/s under winter conditions and 679 l/s under summer conditions.

Aquifer discharge is via seepage to streams and drains, and discharge out to sea (through flow). Losses of groundwater due to spring flow have been estimated as 1162 l/s under winter conditions and 811 l/s under summer conditions. Aquifer through flow for the whole groundwater system has been estimated as 1865 l/s under winter conditions and 1635 l/s under summer conditions.

5. WATER CHEMISTRY

5.1 INTRODUCTION

The water sampling programme was undertaken in order to be able to identify and describe the chemistry of the water at the sample sites and any resulting regional variations in water quality. It was also hoped that aquifers could be defined by specific chemical fingerprints in order to help with the distinction between aquifers. Any aquifer specific chemical patterns could then be used to clarify whether Brown and Taylor's separation of Aquifer 2 into a flowing and non-flowing artesian aquifer was viable.

The sampling sites, as shown in Figure 5.1, were selected to give an even coverage of the Kaikoura Plains. Well identification numbers and other details about the sample site are given in Appendix X. Samples were collected and analysed on two occasions, the first batch of samples were collected in early October 1994 and the second batch of samples in February 1995. In the first round of sampling eighteen samples were taken from sites on the Kaikoura Plains. Of these eighteen samples, three were of surface water from the Kowhai and Waimangarara Rivers and Luke Creek, six were of groundwater from confined Aquifer 2, and nine of groundwater from the unconfined Aquifer 1. These same sits were then used again in the second round of sampling with the exception of the surface water sites (1,2&3) which were only sampled in the first round of sampling as was site 12 (O31/264).

5.2 PREVIOUS SAMPLING

Surface water quality on the Kaikoura Plains has been monitored in two previous surveys, first in 1977-78 by the Marlborough Catchment and Regional Water Board (Bargh, 1978), and most recently in 1990-91 by the Nelson-Marlborough Regional Council (Rae & Shearer, 1991). Both of these surveys focused on Lyell Creek and its main tributary, Warren's Creek. The survey by Bargh (1978) found the waters of Warren's and particularly Lyell Creek to be highly polluted with partially treated sewerage, piggery and cowshed effluent, industrial effluent from the Kaikoura Dairy Co-op factory, and various other pollutants such as rotting sheeps carcasses and waste oil.

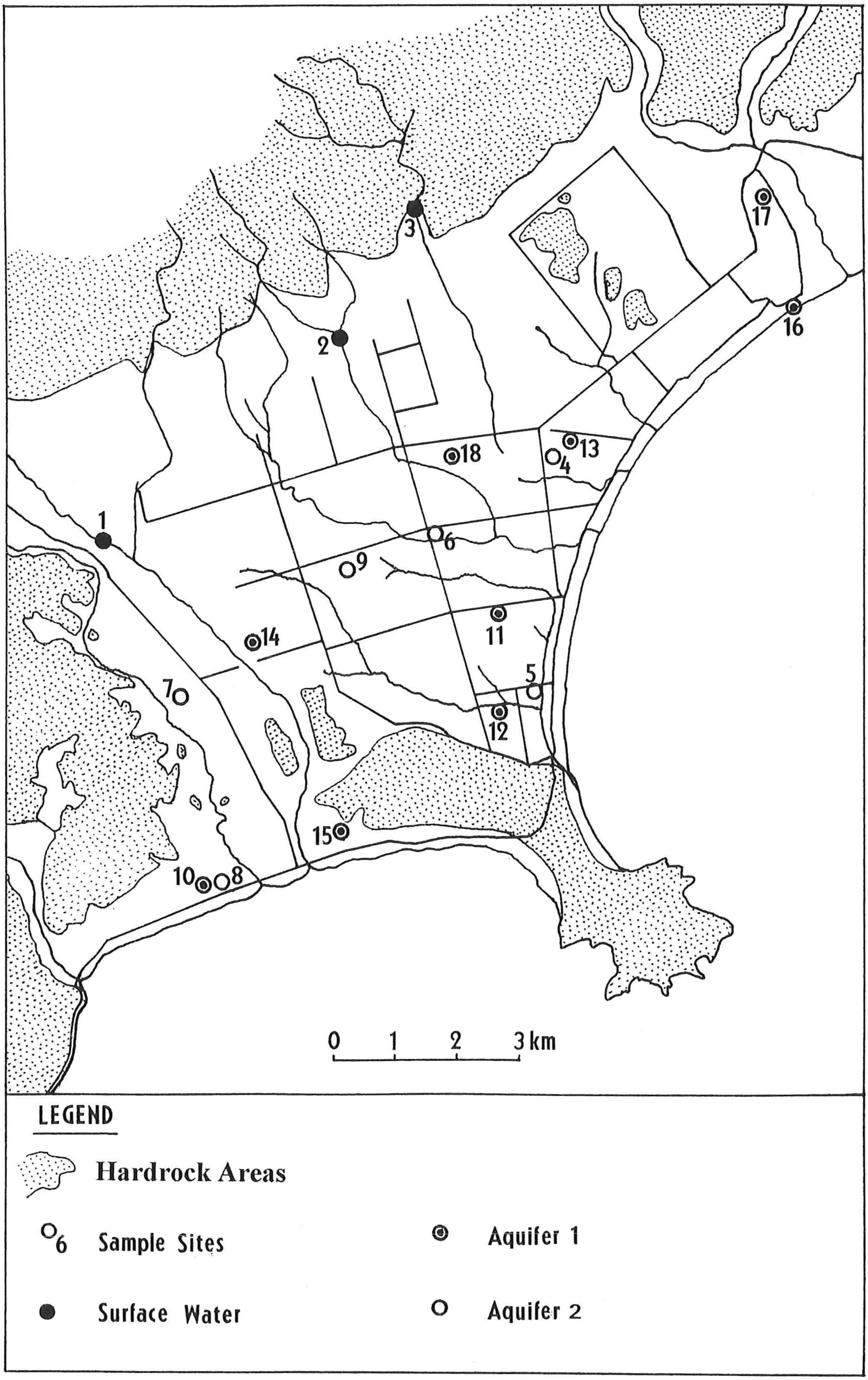


Figure 5.1. Water Chemistry Sample sites.

The survey by Rae and Shearer (1991) found that while there had been an obvious improvement in water quality since the cessation of discharging sewerage into Lyell Creek, there was still a significant level of pollution which appeared to have its origins in the rural sector. However, Lyell and Warrens Creeks were not included in the present sampling program as they are not expected to contribute significantly to the regional groundwater system as both Warren's Creek and Lyell Creek are spring fed, and this upwards flow direction of groundwater means that there is little chance of water from either of these creeks entering the groundwater system.

Previous tests on the quality of groundwater are more extensively than those of surface water, although the tests have been mostly on individual wells and for a limited number of determinants rather than an extensive survey. As such these earlier results are of little use to the present study but do give a basis for comparison. Between 1944 and 1991 there were 34 water quality analyses for varying determinands carried out on samples from 21 individual wells. Of these, three of the previously tested wells coincide with the wells in the present study.

5.3 METHODOLOGY

On both sampling occasions the samples were collected over two days and were analysed by the Canterbury Regional Council laboratory in Christchurch. Due to time restrictions the samples were collected in the morning and transported back to Christchurch to be analysed that afternoon. This was to ensure that reliable results were obtained as some of the determinands, especially pH, are prone to change with time due to the occurrence of equilibrium reactions within the water.

The groundwater samples were all collected by pumping with either a portable surface pump or, where possible an installed pump, with the exception of samples 4 and 5 which were flowing artesian wells and did not require pumping. The wells were pumped or allowed to flow for a period sufficient to allow a volume of water ten times the volume of the bore to be removed. This period of time ranged from 15 - 20 minutes for small diameter pumped bores to overnight for the free flowing artesian bore in Hawthorne Road (sample site 5). Pumping for this length of time also allowed any foreign water or contaminants to be flushed out of the pump. As a further precaution against microbiological contamination of the samples, the pump outlets or taps used to collect the samples were flamed with a gas torch to sterilize them. The surface water samples were collected by gently submersing the sample bottles and allowing them to slowly fill. Groundwater sample 4 was collected in a similar fashion to the surface water samples as it is continually flowing.

At each site three discreet samples were taken, one for microbiological analysis, one for the measuring of physical properties and the third for the analysis of ion concentrations.. The microbiological contaminants tested for were faecal coliforms and total coliforms; the physical properties tested for were pH and conductivity; and the major ions consisted of calcium, sodium, magnesium, potassium, bicarbonate alkalinity, sulphate, and chloride. Manganese and iron analyses were only included in the second round of sampling. Full results of the laboratory analyses are given in Appendix X.

In the first round of testing, the procedure used in analysing the samples for dissolved calcium underestimated the concentrations for samples high in calcium. This problem was uncovered when it was found that an ion balance could only be achieved on these samples with an unacceptably large error. Estimated values for calcium were then substituted into the ion balance until the optimum value was obtained. This was the value which gave the smallest degree of error. This value was then adopted as the "true" value.

The method of analysing for calcium used in the first round of sampling measured the concentration of dissolved calcium. While this is an acceptable method for water with low concentrations of calcium it is suspected that with the higher levels of calcium in the Kaikoura groundwater calcium was precipitating out of solution. As a result of this calcium concentrations were being underestimated. In the second round of testing an acid dissolved method of analysis was used as it is a more accurate technique for measuring high levels of calcium Dissolved calcium was also analysed in the second round of sampling to give a comparison with the acid dissolved analysis. Although the second technique gave higher concentrations of calcium than the first, the ion balance still had a fairly large, but acceptable, degree of error, the reasons for which remain unexplained.

The results of both rounds of testing are discussed in the following sections in terms of both water chemistry and water quality. The water chemistry section discusses the results with a view to determining specific chemical trends, either within or between the aquifers, while the water quality section compares the results with drinking water standards and discusses the suitability of the water for different utilization.

5.4 WATER CHEMISTRY

5.4.1 Major Ions

The major ions consist of calcium, magnesium, sodium, potassium, bicarbonate, sulphate and chloride which typically constitute more than 90% of all ions in natural waters. The major ion content of the Kaikoura Plains surface water and groundwater is presented in Figure 5.2 which depicts the data as obtained from the testing program, and also in Table 5.1 which shows this data in a more definitive form.

SURFACE WATER

	No. of samples	Mean	Max.	Min.
Ca	3	19.7	24	16
Mg	3	1.9	2.2	1.6
Na	3	3.4	3.4	3.3
K	3	0.83	1.3	0.5
Cl	3	2.3	3	2
SO_4	3	11.7	16	7
HCO_3	3	56.3	68	49

AQUIFER 1

	No. of samples	Mean	Max.	Min.
Ca	9	29.9	56	12
Mg	9	6.5	25	2
Na	9	11.7	34	4.4
K	9	2.3	4.1	0.9
Cl	9	10	27	2
SO_4	9	13.4	21	5
HCO_3	9	119.6	370	44

Table 5.1. Major ion data for Kaikoura Plains surface and groundwater samples. (Units are g/m^3).[continued over page]

AQUIFER 2

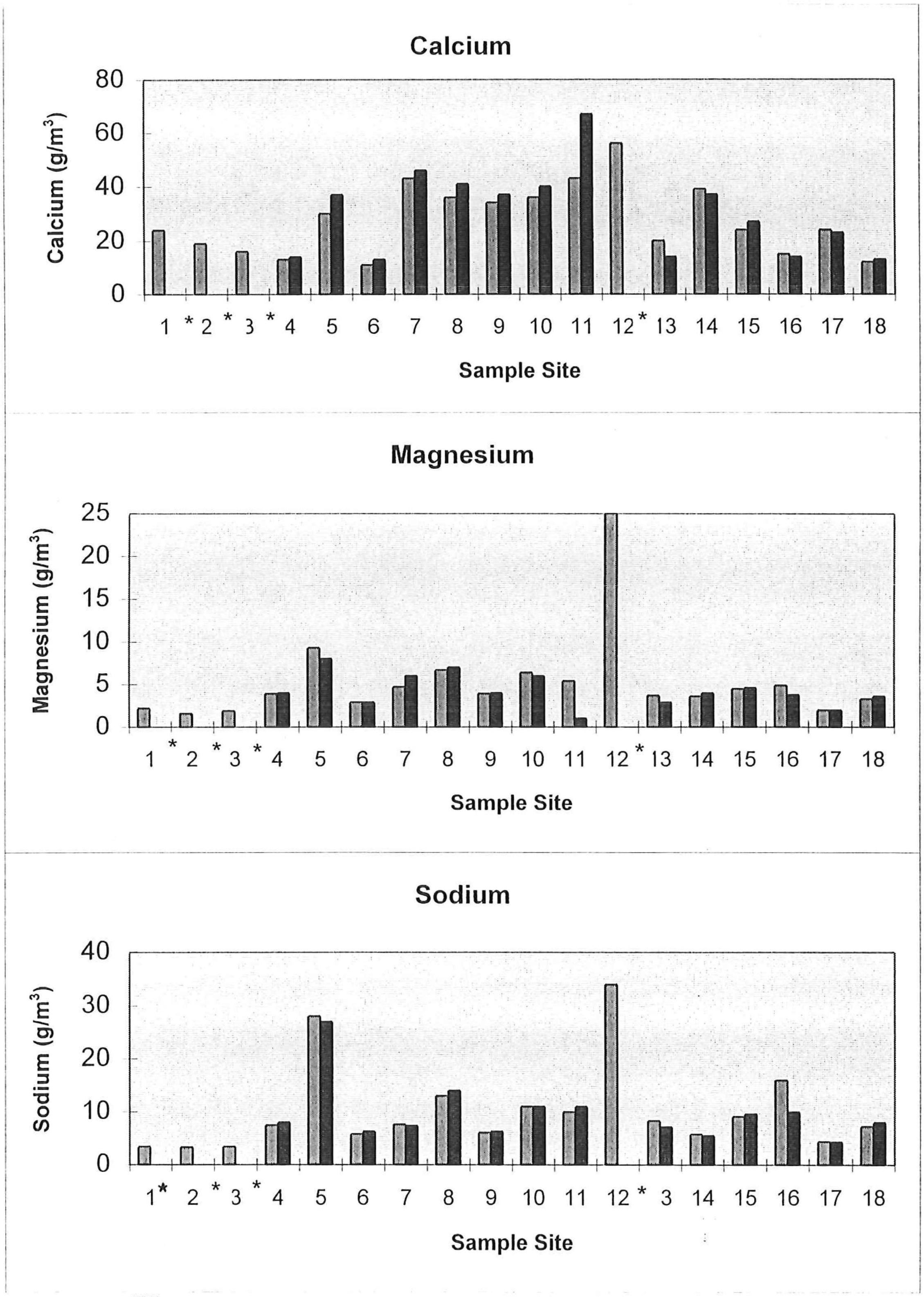
	No. of samples	Mean	Max.	Min.
Ca	6	27.8	43	11
Mg	6	5.2	9.3	2.9
Na	6	11.3	28	5.8
K	6	1.2	1.5	0.8
Cl	6	5.5	8	4
SO_4	6	8.5	14	5
HCO_3	6	120.7	200	56

Table 5.1 continued.

Sample sites displaying high ion concentrations in comparison to average ion concentrations are shown in table 5.2. The location of these sample sites 5 and 12 near Hawthorne and Rorrisons Roads is close to the coast on drained and developed swamp land, site 12 is located in Aquifer 1 and site 5 is located in Aquifer 2. The subsurface geology consists of low permeability swamp, estuarine and flood deposits overlying alluvial and beach deposits and the high sodium levels with respect to calcium and magnesium, suggest the presence of older and hence more chemically evolved water. The high bicarbonate levels, especially from site 12, may indicate the production of CO_2 within the aquifer which would be consistent with subsurface swamp deposits. Sample site 16 is located within 100 metres from the coast and displays elevated concentrations of chloride. However the concentration is not high enough to indicate saltwater intrusion, instead this elevated chloride concentration is probably due to the influence of sea spray infiltrating into the aquifer with rainfall.

Sample Site	Ca	Mg	Na	HCO_3	SO_4	Cl
Site 5	-	-	28 [27]	200 [210]	-	-
Site 12	-	25	34	370	-	-
Site 16	-	-	-	-	-	27

Table 5.2. High ion concentrations (g/m^3) and their locations. [] indicates result obtained in second round of sampling.

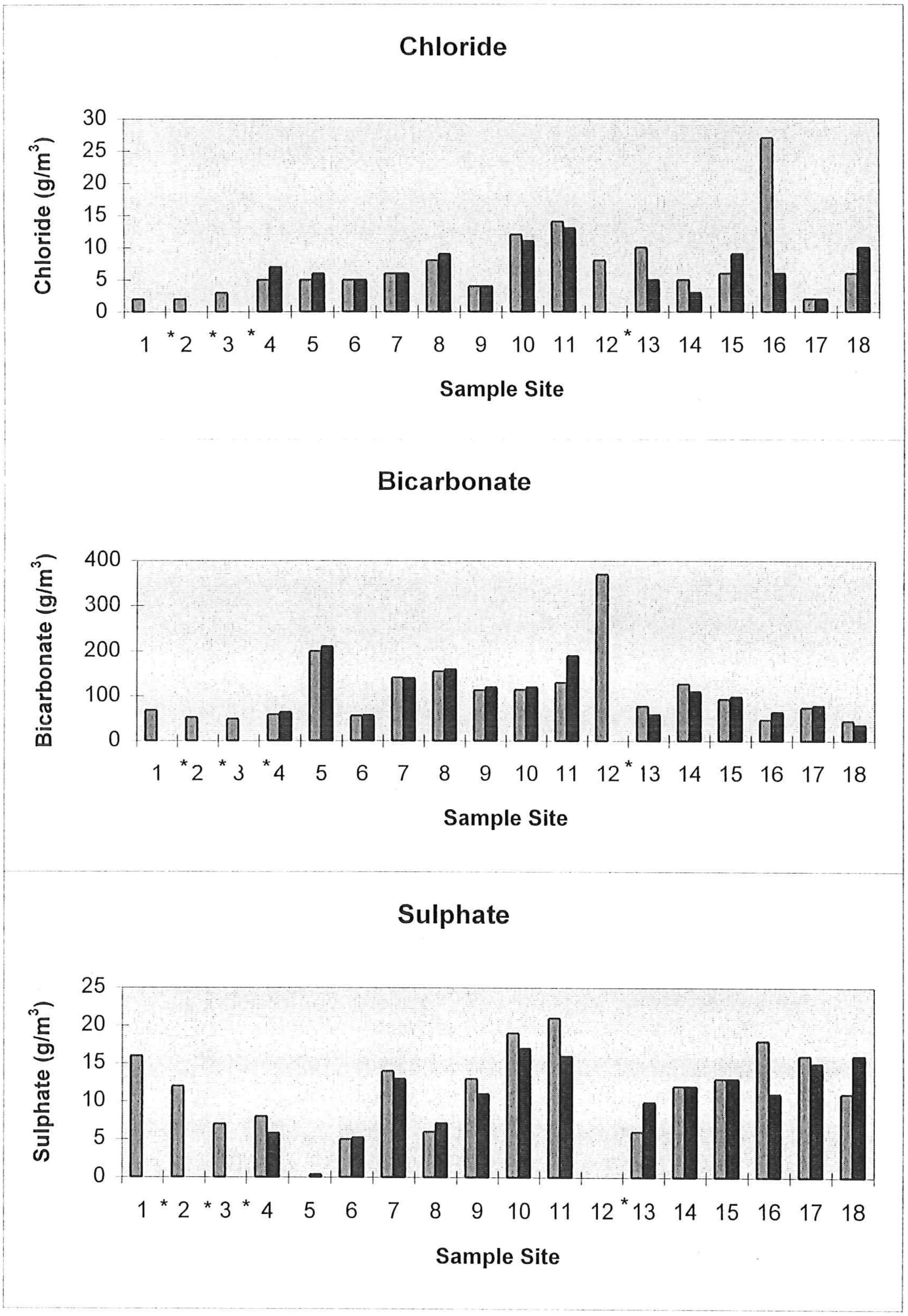


Sites sampled October, 1994.

Sites sampled February, 1995.

* Site not re-sampled.

Figure 5.2a. The Three Major Cations.



Sites Sampled October, 1994.
Sites Sampled February, 1995.
* Site not resampled

Figure 5.2b. The Major Anion Concentrations.

A general evolutionary trend in groundwater can be observed in Figure 5.3 where a comparison is made between average surface water and groundwater compositions. There is a marked increase in chloride, sodium, magnesium and bicarbonate with a small increase in calcium and only a slight increase in sulphate. Aquifer 1 shows a greater increase in dissolved solids than does Aquifer 2, this could be due to the effect of rainfall infiltration leaching chemicals out of the soils and transporting them to groundwater. Thus as Aquifer 1 has a greater component of rainfall recharge it has higher levels of total dissolved solids than Aquifer 2.

5.4.2 Piper Trilinear Diagram

In Figure 5.4 the major ion concentrations are presented on Piper trilinear plots of groundwater data for both rounds of sampling. The cation fields show a linear transition from Ca dominated water to Ca-Mg-Na water in round one; and to Ca and Na dominated water in round two. This follows the general cation replacement series of (Mathess, 1982):

$$Ca^{2+} \rightarrow Ca^{2+} + Mg^{2+} \rightarrow Na^{+}$$

The transition shown in Figure 5.4 also correlates with relative distances from recharge sources and therefore presumably with the age of the water.

Bicarbonate was the dominant anion in all but one of the groundwater samples from Kaikoura. According to the Chebotarev geochemical sequence (Freeze and Cherry, 1989), in most ground water systems there is a transition from bicarbonate waters to sulphate waters due to the replacement of bicarbonate by sulphate with increasing distance from the recharge source. This anion replacement series follows the general trend of:

$$HCO_3 \rightarrow SO_4 \rightarrow Cl$$

This trend is not readily apparent in the Kaikoura groundwater system, perhaps indicating that the Kaikoura Plains are not extensive enough for groundwaters to have a long enough residence time to evolve fully. However, elevated bicarbonate levels can result from the production of CO_2 within the aquifer. This would be consistent with the presence of swamp and peat deposits and the decomposition of organic material.

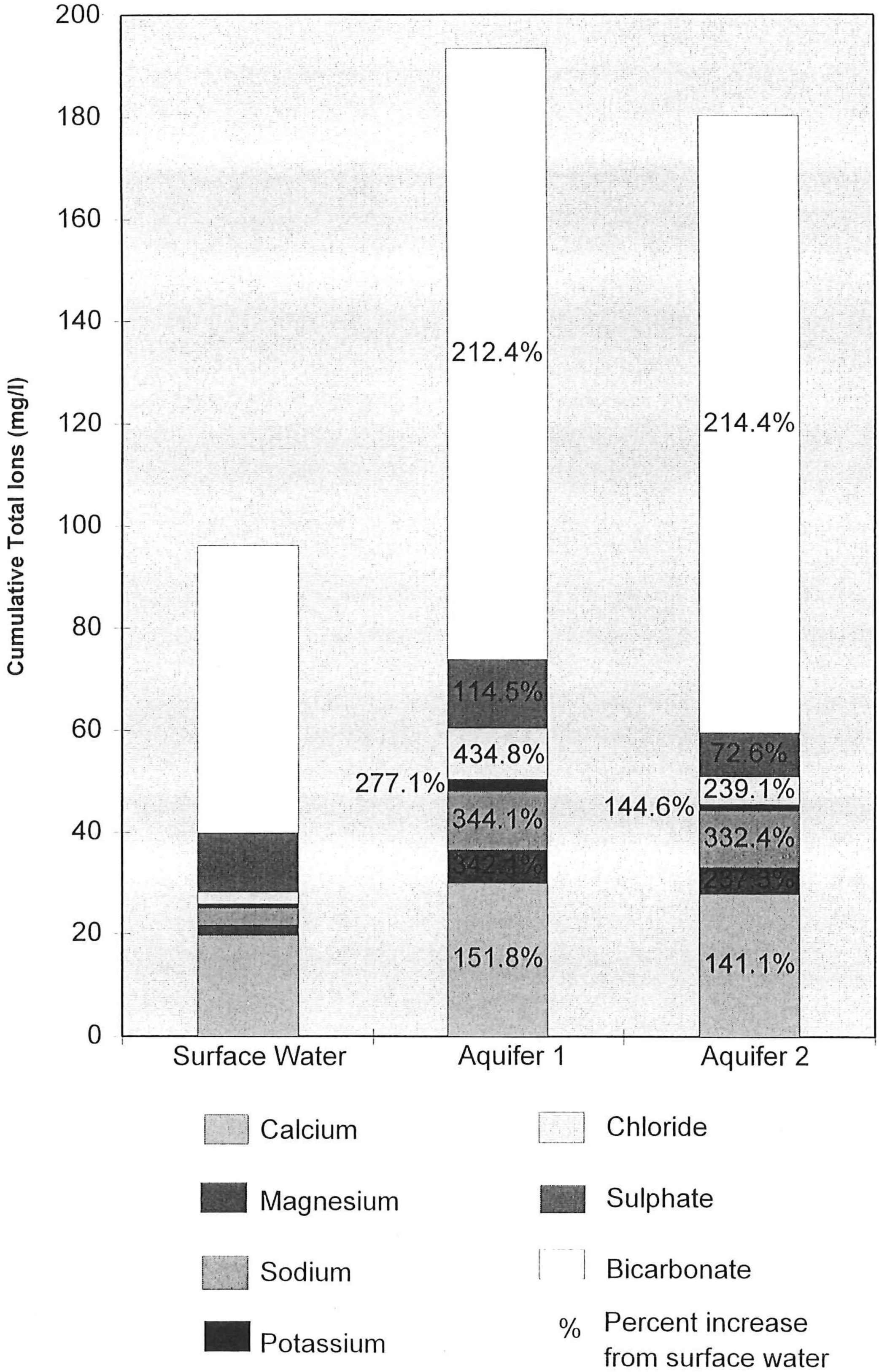
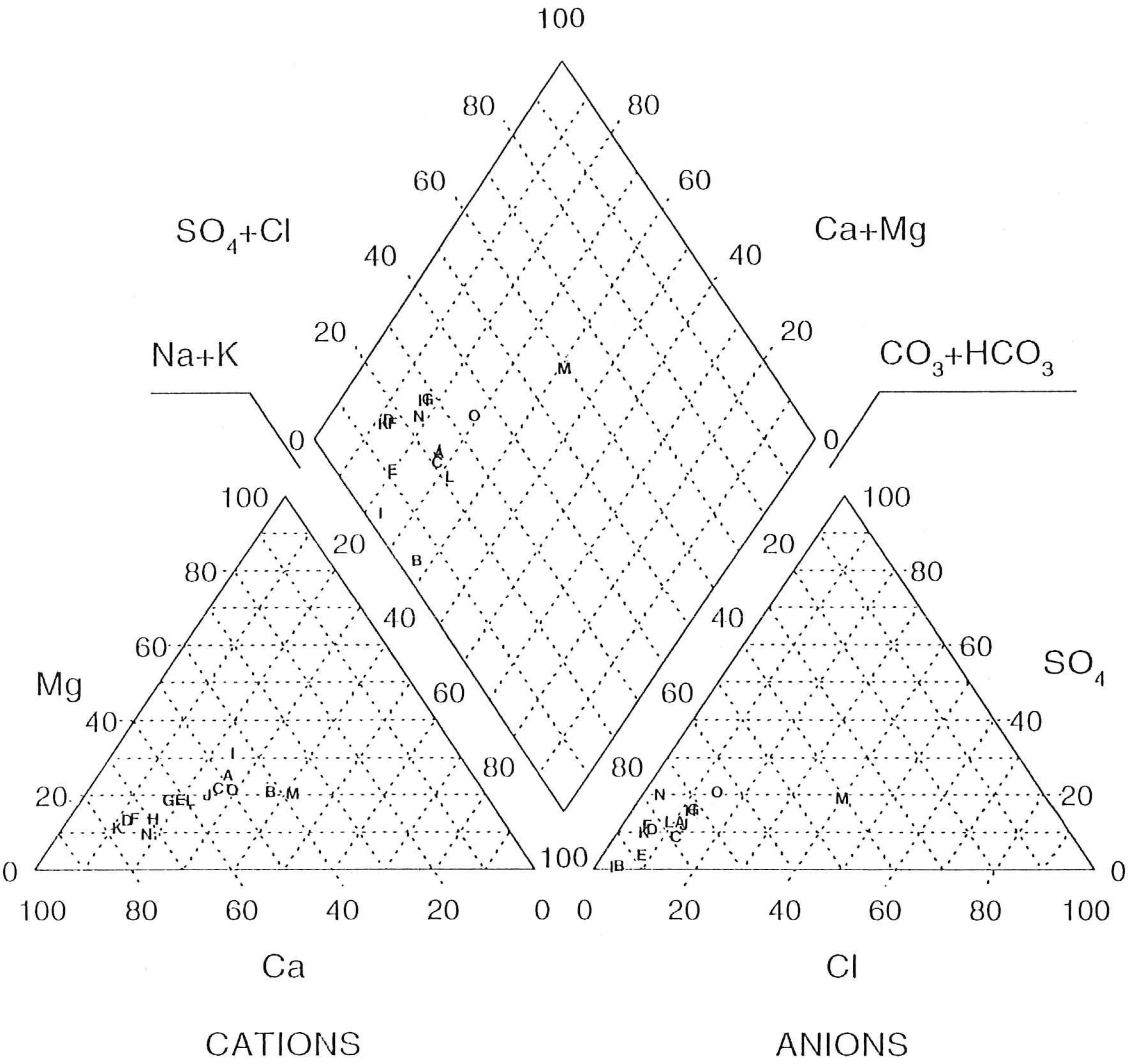
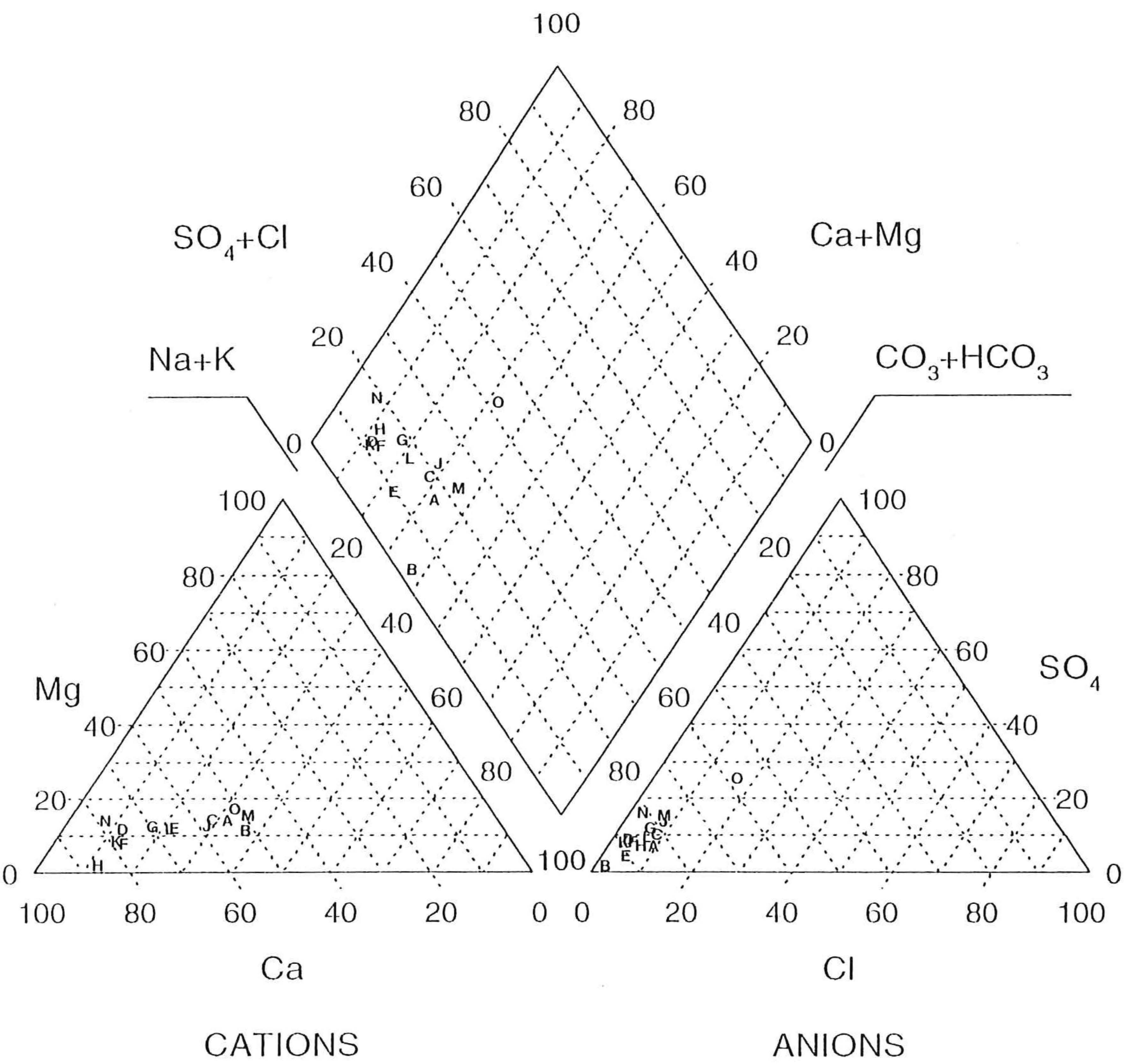


Figure 5.3. Comparison of mean surface water and mean groundwater major ion concentrations.



Symbol	Sample Site	Symbol	Sample Site
A	4	I	12
B	5	J	13
C	6	K	14
D	7	L	15
E	8	M	16
F	9	N	17
G	10	O	18
H	11		

Figure 5.4a. Piper trilinear plot of major ion data from the first round of sampling (after Piper, 1944).



Symbol	Sample Site
A	4
B	5
C	6
D	7
E	8
F	9
G	10

Symbol	Sample Site
H	11
J	13
K	14
L	15
M	16
N	17
O	18

Figure 5.4b. Piper trilinear plot of major ion data from the second round of sampling (after Piper, 1944).

A distinct outlier on the trilinear plot of the first round of sampling is site 16. This sample site is located in a low lying area within 50m of the sea and shows distinctly higher levels of chloride than the other samples. This could be due to any one of three reasons: 1. minor salt water incursion occurring during high seas, 2. the effect of sea spray leaching into the groundwater system, or 3. salt from buried beach deposits dissolving into the groundwater. However in the second round of sampling this site did not show the same effect, indicating that chloride levels in this locality are quite variable. If these elevated chloride levels were the result of saltwater incursion, the concentration of chloride observed would be expected to be much higher and probably less variable. It is therefore more likely that the elevated chloride levels observed are the result of either sea spray residue being leached into groundwater or salt associated with buried beach deposits being dissolved into groundwater, neither of these sources would be expected to result in extremely high chloride levels and both are expected to be very variable, depending on volumes of water moving through the aquifer and rates of rainfall infiltration.

Both Aquifers 1 and 2 show no real differences in plot positions on the trilinear diagrams indicating that both must be subject to much the same aquifer materials and conditions. The cation replacement trend from Ca dominated water to Ca-Mg-Na water is the same for samples from both Aquifer 1 and Aquifer 2, and both Aquifer 1 and Aquifer 2 consist almost exclusively of bicarbonate dominated water.

5.4.3 Magnesium to Calcium Ratios

In general, selective cation exchange by aquifer materials favours the absorption of calcium with respect to magnesium, and the general cation replacement series is from Ca⇒Mg⇒Na. Thus older groundwaters usually have higher magnesium to calcium ratios. Magnesium to calcium ratios for the Kaikoura samples are shown in Figure 5.5. In this case the increased magnesium to calcium ratio correlates with increased distance from recharge source and therefore presumably with greater residence time within the aquifer. Both Aquifer 1 and Aquifer 2 display a similar range of calcium to magnesium ratios. The highest magnesium to calcium ratio was obtained from site 5, which is located in Aquifer 1, in predominantly silt and swamp deposits of low permeability. This low permeability suggests very slow water movement, hence a greater residence time within the aquifer and hence the high magnesium to calcium ratio.

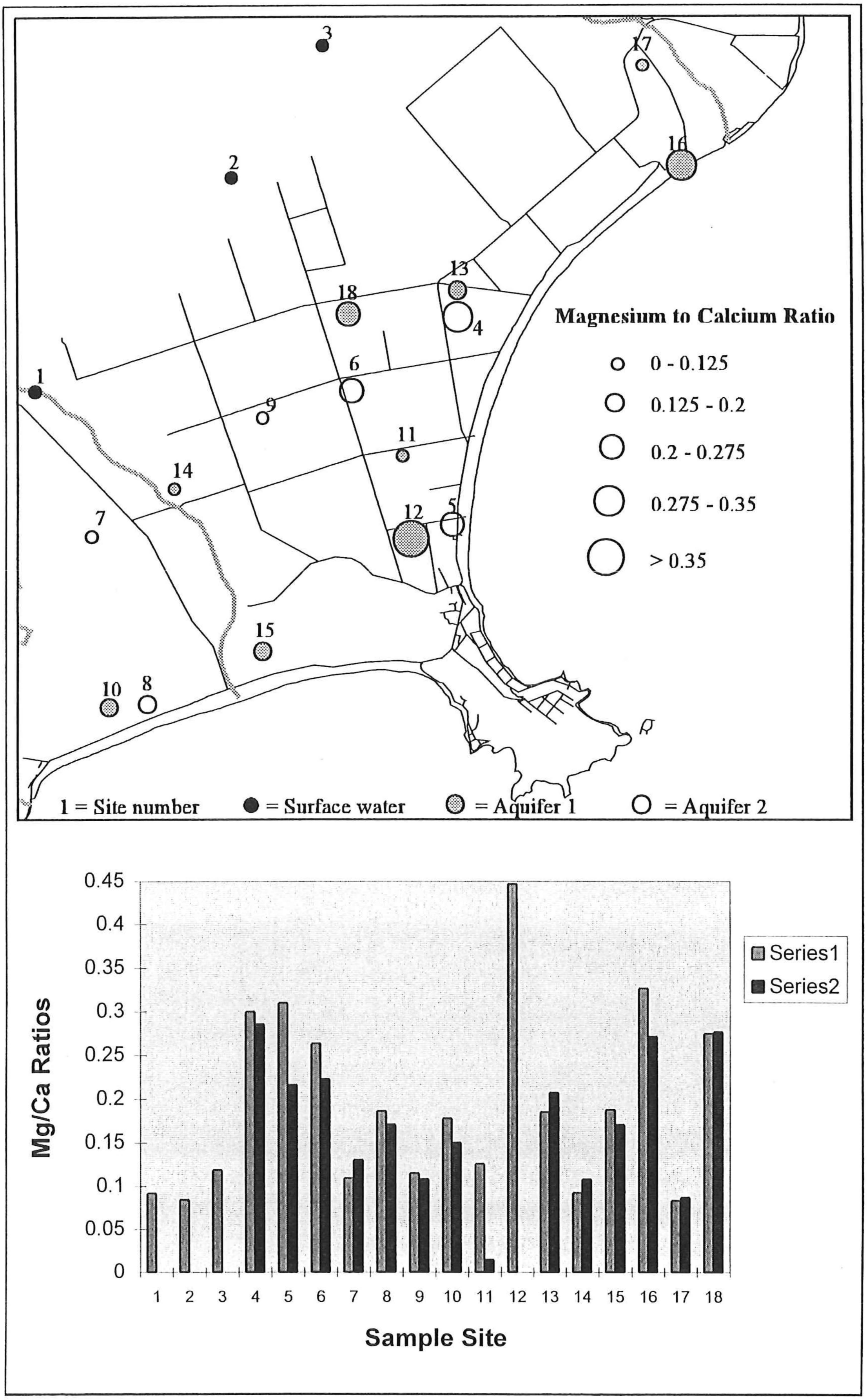


Figure 5.5. Magnesium / calcium ratios and spatial variation.

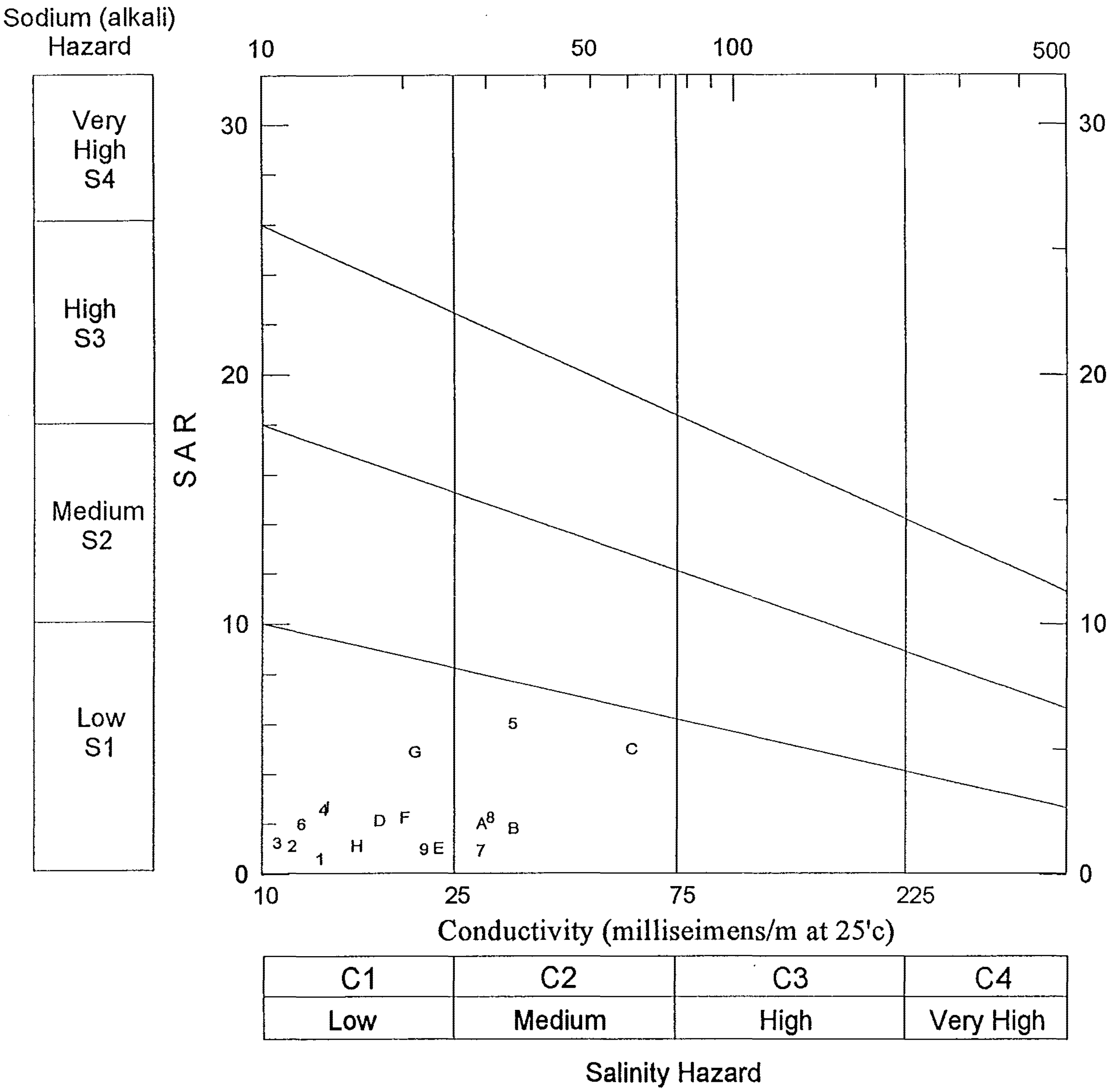
5.4.4 Sodium Absorption Ratios

The sodium absorption ratio (SAR) of a water is a measure of the water's ability to replace calcium and magnesium with sodium, and is obtained using the following equation (Mathess, 1984) where the concentrations are expressed in meq/l:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

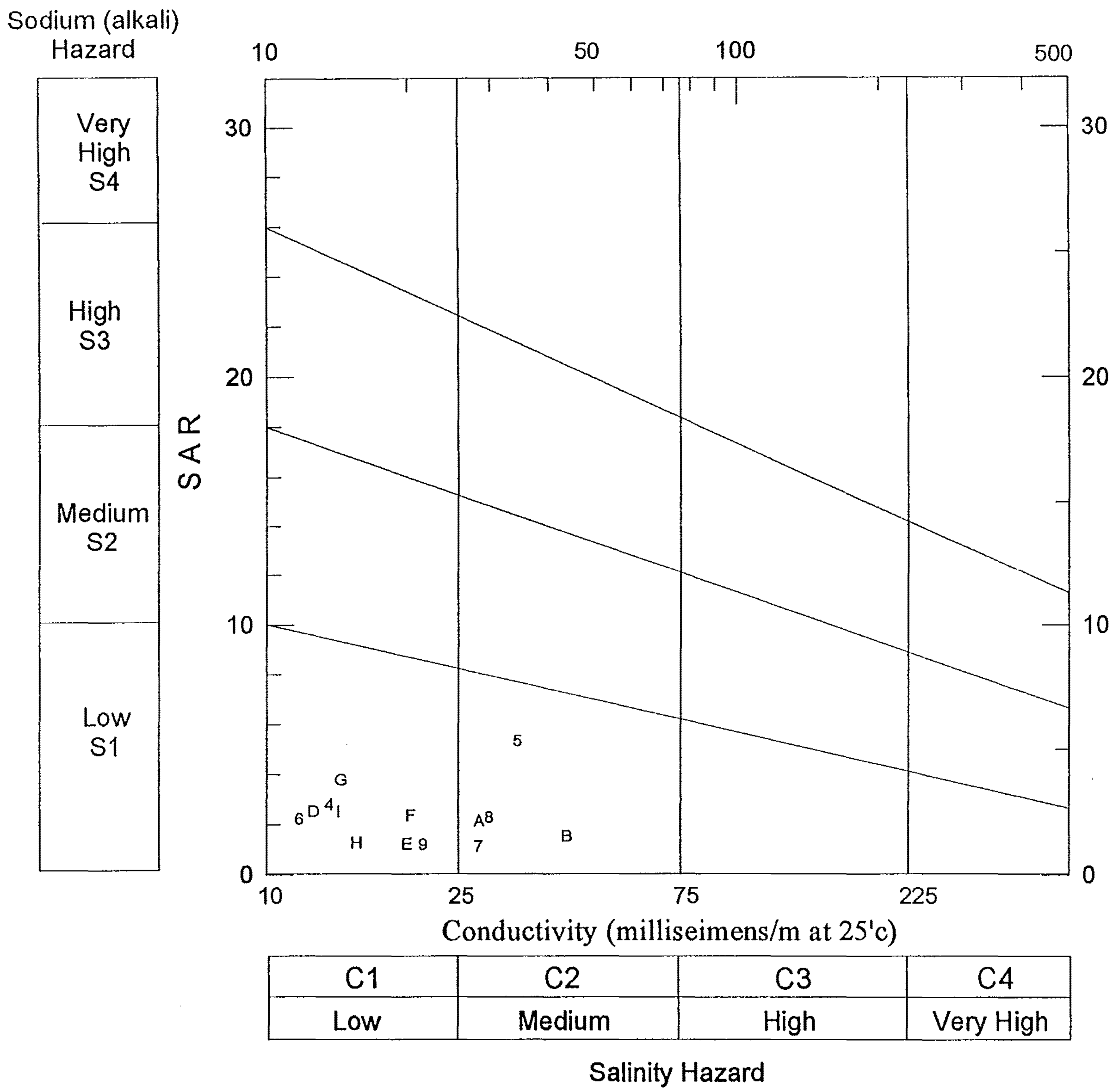
In sediments which contain a high proportion of clay and in which the cations in the water are not in equilibrium with the cations in the double layer of clay particles, the resulting ion exchange changes the state of the clay from a flocculated to a dispersed state (Mathess, 1984). This change results in a corresponding decrease in the hydraulic conductivity of the sediment as a soil with clay particles in a floculated state behaves like coarser textured soil than when they clay particles are dispersed. This effect would be insignificant sand or gravel aquifers such as those of the Kaikoura groundwater system, and of greater concern for heavy soils, clays and shales for example. However it could have implications for the amount of rainfall or irrigation recharge received by an aquifer.

The SAR of a water source also has implications for its use for irrigation. Figure 5.6 shows plots of groundwater conductivity against SAR with the corresponding salinity hazard and alkali hazard. The hazard values give an indication as to the suitability of a water for irrigation of different types of crops. All the water samples rated a low to medium salinity hazard with the majority of samples falling into the low salinity hazard class. Water of low salinity hazard is generally suitable for irrigation of most crops and most soil types. Water of moderate salinity hazard should not be used to irrigate crops with a low salt tolerance or those growing in soils of low permeability. All the water samples rated a low alkali hazard which is generally acceptable for irrigating most crop and soil types except for very sensitive crops such as deciduous fruits, nuts, citrus and avocados which require the SAR to be less than 2 (Bouwer, 1978).



Symbol	Sample Site	Symbol	Sample Site
1	1	A	10
2	2	B	11
3	3	C	12
4	4	D	13
5	5	E	14
6	6	F	15
7	7	G	16
8	8	H	17
9	9	I	18

Figure 5.6a. Sodium and salinity hazards for water samples taken during the first round of sampling.



Symbol	Sample Site	Symbol	Sample Site
4	4	B	11
5	5	D	13
6	6	E	14
7	7	F	15
8	8	G	16
9	9	H	17
A	10	I	18

Figure 5.6b. Sodium and salinity hazards for water samples taken during the second round of sampling.

5.5 PHYSICAL PROPERTIES

5.5.1 Conductivity

Specific electrical conductance can vary markedly with temperature and it is therefore necessary to specify the temperature of measurement (in this case 25°C). The conductivity of a water is proportional to the amount of dissolved ions in the water and hence to the salinity of the water (Bouwer, 1978). The typical conductivity of common distilled water is generally in the region of 0.5 to 5 mS/m (Mathess, 1982). The values obtained for conductivity are plotted on Figure 5.7 and show a general increase towards the coast. This increase in conductivity correlates with distance from the groundwater source and therefore, presumably, correlates with the age of the water; as the longer the water resides in the aquifer, the more electrolytes will be dissolved. Figure 5.8 shows a direct correlation between conductivity and total dissolved solids and thus total dissolved solids within Kaikoura groundwater can be estimated as:

$$\text{Total Dissolved Solids (mg/l)} = \text{Conductivity (mS/m)} \times 8.55$$

This relationship applies to both Aquifer 1 and Aquifer 2 as there is no distinct differences between the range of conductivities of Aquifers 1 and 2.

5.5.2. pH.

pH or hydrogen ion activity also varies with temperature; a neutral pH varies from 6.92 at 30°C to 7.48 at 0°C. The neutral pH at 25°C however is 7.00, and this is the temperature at which laboratory measurements are usually taken. The hydrogen ion activity results as plotted in Figure 5.9 show no distinct trend and show no real differences between Aquifers 1 and 2. However, the majority of groundwater samples with low pH values indicates either a reducing environment high in CO_2, which is consistent with the swamp and peat deposits known to exist in the subsurface, or in the unconfined aquifers CO_2 may be added from the soil profile. pH may also be affected by oxidation of dissolved ferrous iron. The groundwater of the Kaikoura area traditionally has high levels of dissolved iron and in many cases is discoloured by its oxidised form.

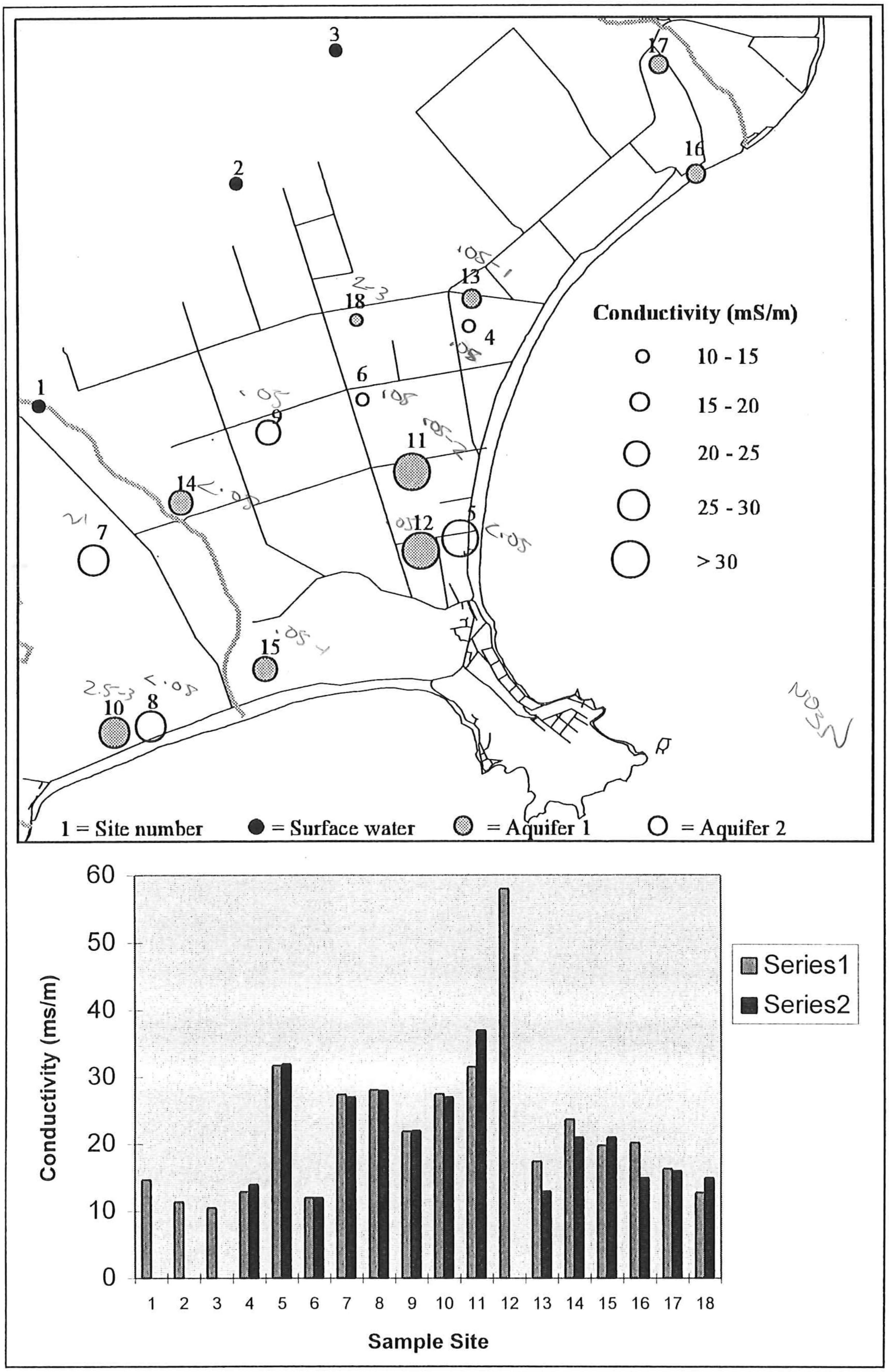


Figure 5.7. Conductivity values and spatial variation.

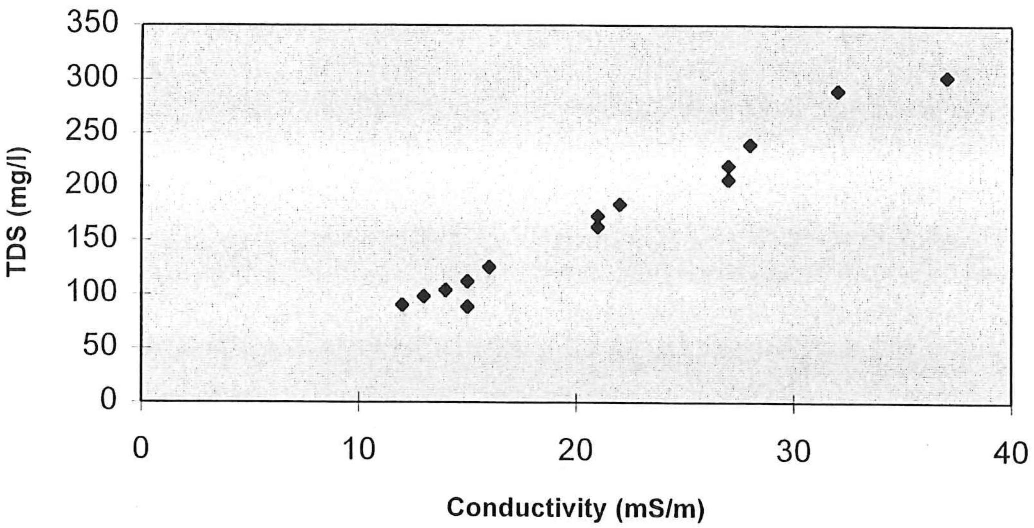


Figure 5.8. Correlation between conductivity and total dissolved solids.

5.6 WATER QUALITY

5.6.1 Drinking Water Standards

Drinking water standards are set out in order to determine the acceptability of a water for a specific use. The Drinking Water Standards for New Zealand (DWSNZ) (Ministry of Health, 1995) list the maximum concentrations of chemical, microbial and radiological contaminants acceptable for public health in drinking water, as well as discussing aesthetic considerations. Relevant sections of both the 1984 and the new 1995 drinking water standards are given in Appendix X.

While both microbiological and chemical contaminants were assessed, the microbiological contaminants are of most immediate concern because of their potential to cause both acute and widespread health problems. Chemical contaminants rarely lead to acute health problems; before health risks arise the water usually becomes undrinkable due to objectionable taste, odour or appearance. However, chemical contaminants can lead to chronic health problems after prolonged exposure. Of particular concern are chemicals with cumulative deleterious properties such as heavy metals; however, these were not expected to be a contaminant issue in Kaikoura as there are to few potential sources of heavy metal contamination, and no heavy industries.

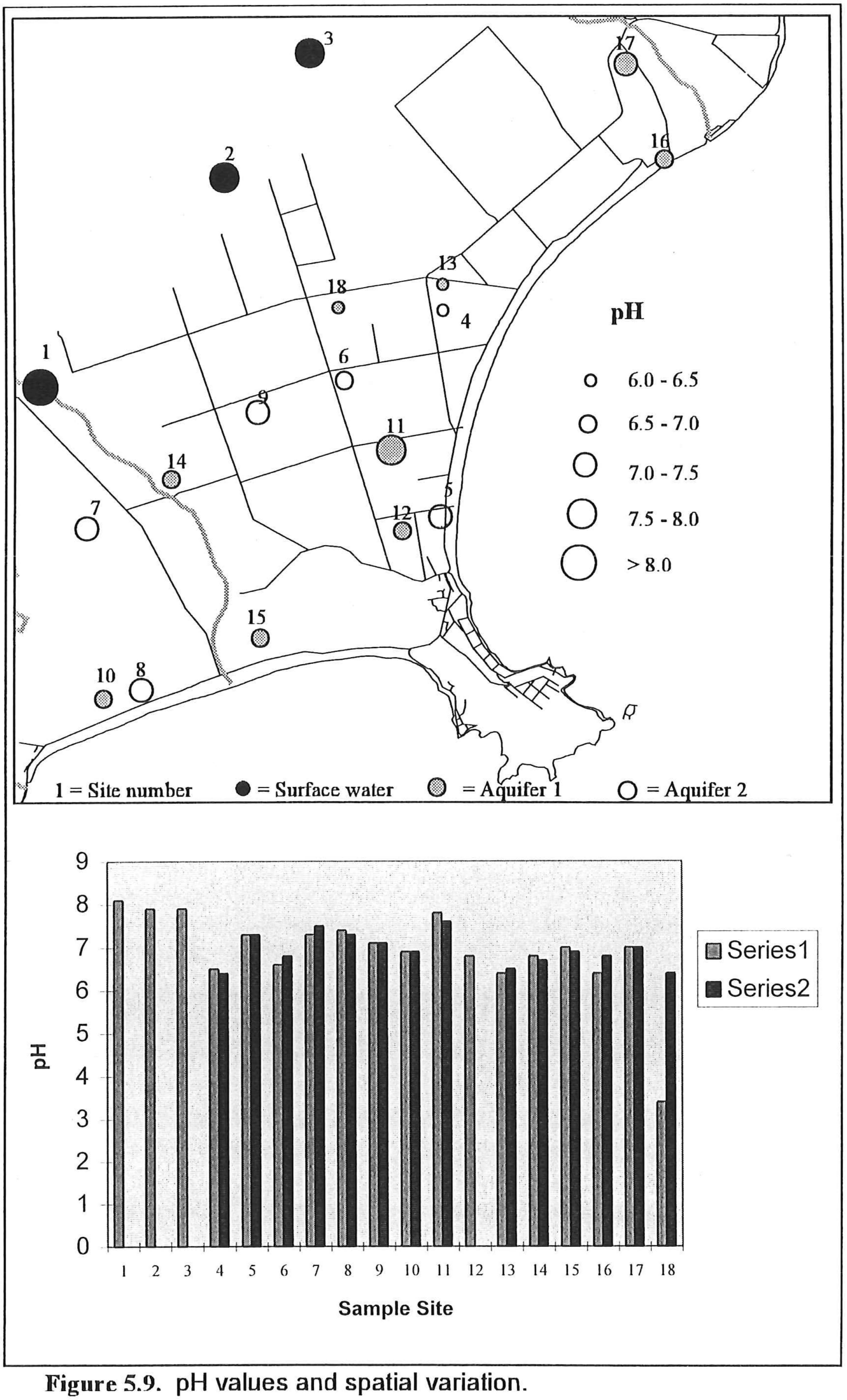
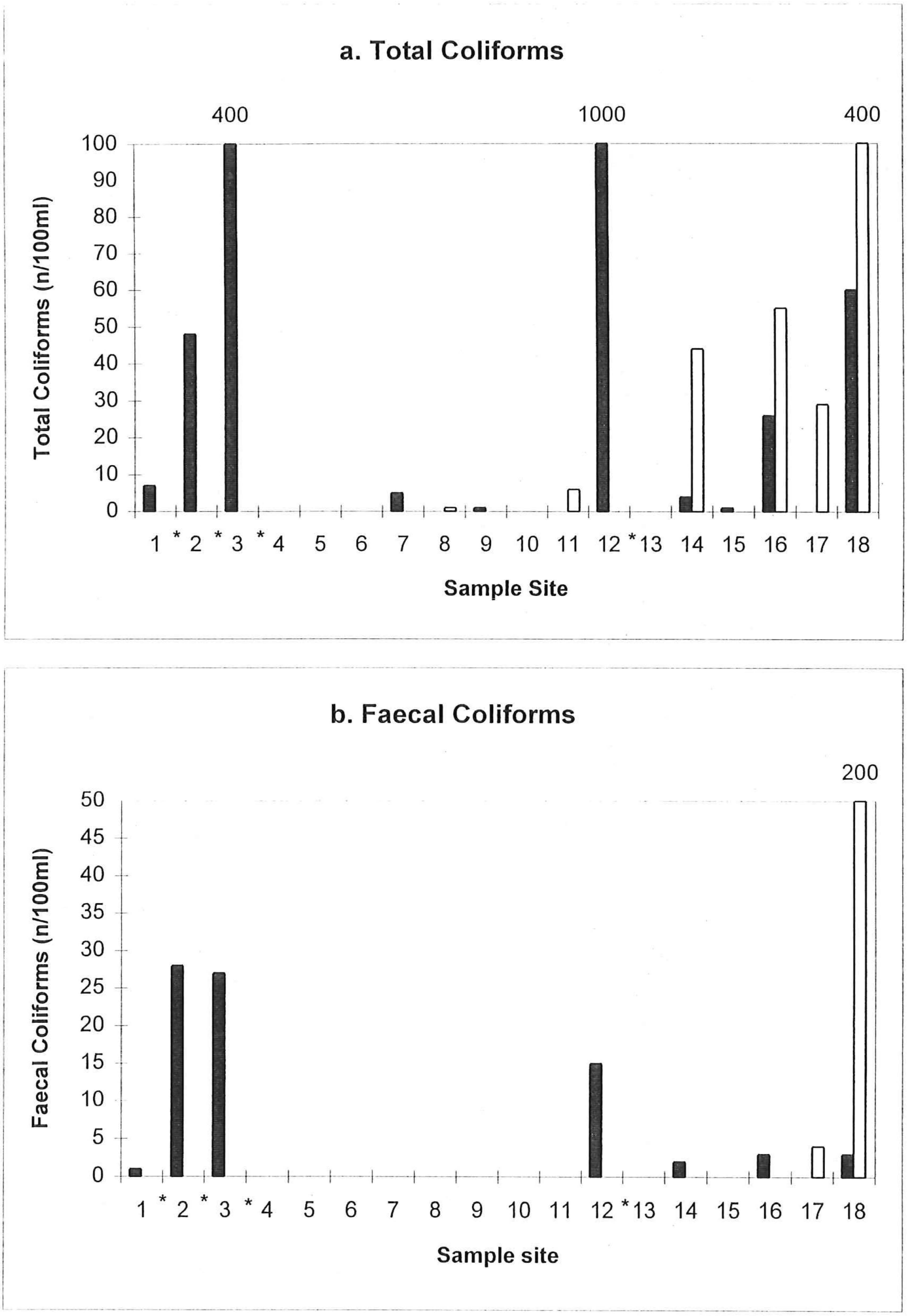


Figure 5.9. pH values and spatial variation.

5.6.2 Microbiological Contaminants

The water samples were analysed for both faecal coliforms and total coliforms, and the results are presented in Figure 5.10. DWSNZ (Ministry of Health, 1995) gives a maximum acceptable value for faecal coliforms of undetectable in 100*ml* of sample with no mention of total coliforms, while DWSNZ (Department of Health, 1984) gives the same guideline value of nil/100*ml* for faecal coliforms and 10/100*ml* for total coliforms. Of the eighteen sites sampled in the first round (Figure 5.10), seven returned excessive values for faecal coliforms (three from surface water and four from Aquifer 1) and ten returned positive results for total coliforms of which four exceeded the 1984 guideline (two surface water and two Aquifer 1). From the second round of sampling, four sites were found to have transgressed the standard for both total and faecal coliforms (Figure 5.10). Both the Waimangarara River and Luke Creek (sample sites 2&3) exceeded the standard for both total and faecal coliforms. These sites were above the influence of contamination related to farming so this microbiological contamination may be due to wild fauna (possums, pigs, birds etc.). In the first round of testing a high faecal coliform count, and very high total coliform count, was obtained from site 12, this well is located directly behind a cow shed and approximately 50m from Warrens Creek, which was found to be badly contaminated by Bargh (1978) and Rae and Shearer (1991). Another pair of extreme values, this time from the second round of testing, was from site 18. This is an unlined well sited in a paddock on a dairy farm and is totally exposed to surface runoff.

In comparison, the differences in numbers of both total and fecal coliforms between sampling rounds suggests that microbiological contamination of groundwater is extremely variable. The results also show that the shallow watertable aquifer is by far more susceptible to microbiological contamination than are confined aquifers; none of the confined aquifer samples tested positive for faecal coliforms with only sites 7 and 9 returning positive, but low, total coliform results. These results indicate that water abstracted from wells located in unconfined aquifers for domestic purposes should be tested for microbiological contaminants on a regular basis. This particularly relevant for households in a rural environment.



Sampled in October, 1994.
Sampled in February, 1995.
* Site not re-sampled.

Figure 5.10. Microbiological Contaminants.

5.6.3 Chemical Determinands of Health Significance

The only chemicals analysed in the samples which are known to have possible adverse health effects were nitrate and manganese. Both nitrate nitrogen and manganese data are presented in Figure 5.11. DWSNZ (Ministry of Health, 1995) gives a maximum acceptable value for nitrate of 50mg/l as NO_3 (equivalent to approximately 4.4mg/l as NO_3-N) and 0.5mg/l for manganese. All samples contained concentrations well below the maximum acceptable values for these determinands, with the exception of site 5 (O31/156) which came close to the manganese limit with a value of 0.48mg/l (Figure 5.11).

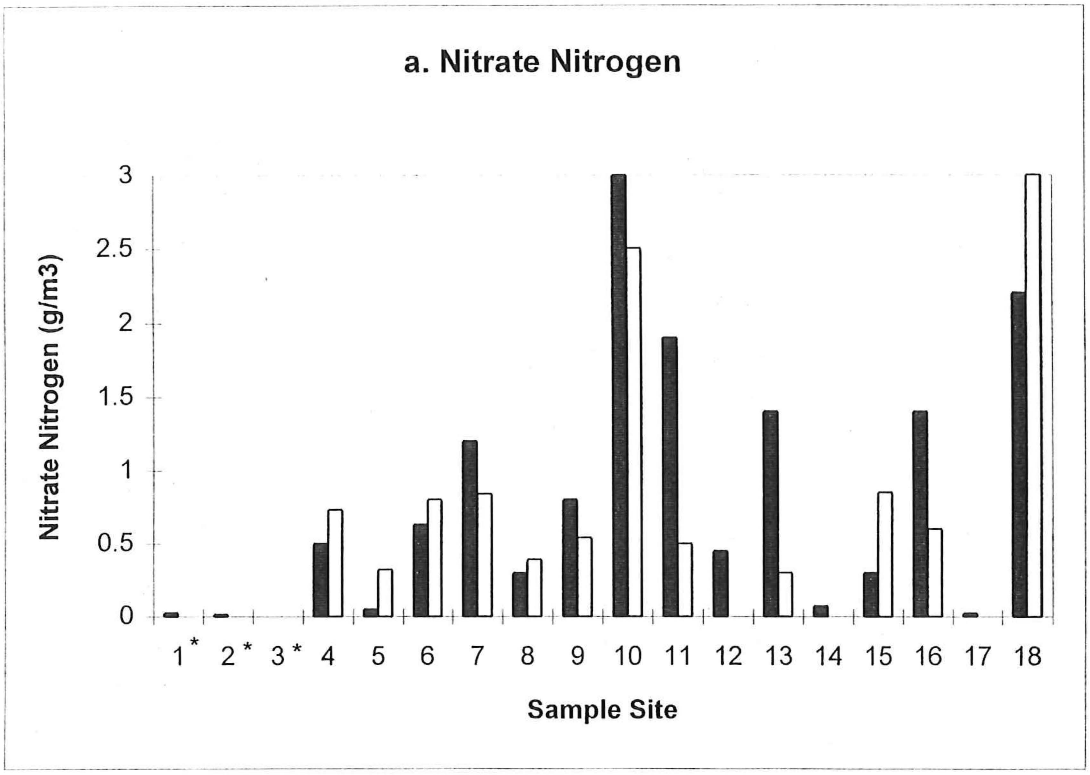
5.6.4 Chemical Determinands of Aesthetic Significance

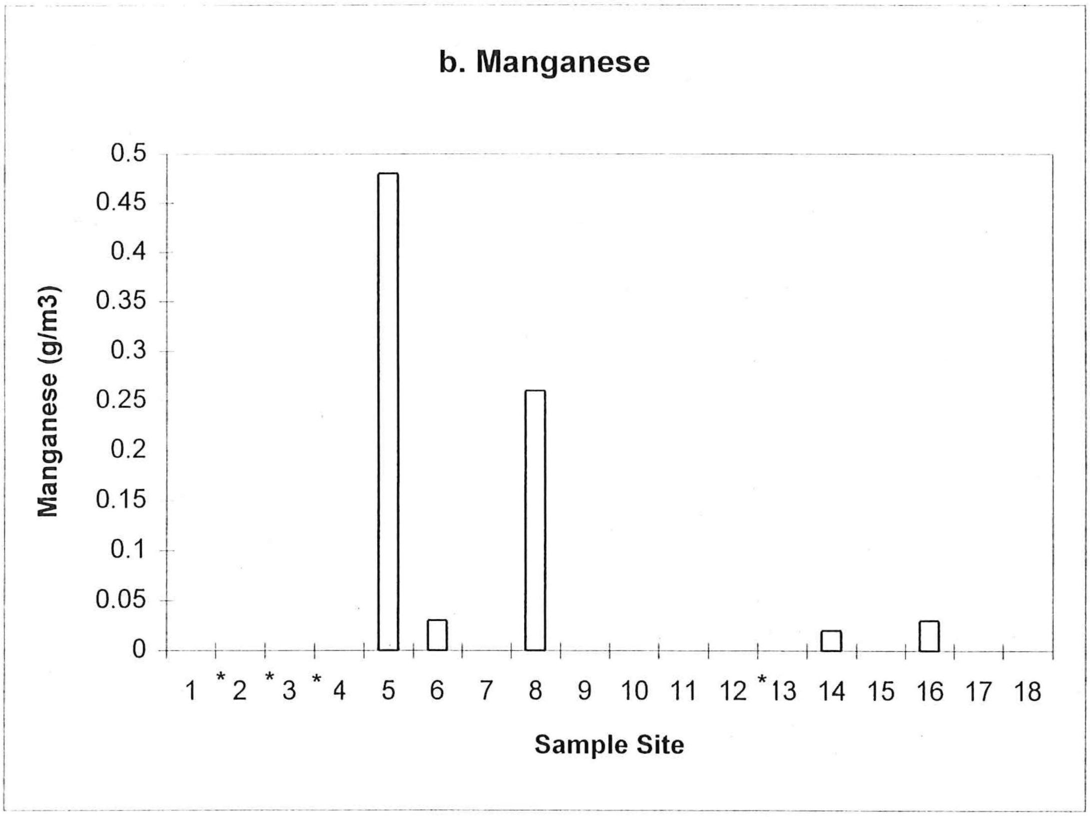
The guideline values set out in DWSNZ (Ministry of Health, 1995) for aesthetic determinands were included as a guide to aesthetically acceptable drinking-water and as such there is no requirement to meet compliance with the standards. However, concentrations of determinands in groundwater which approach and exceed the guideline values will most likely have unacceptable taste, odour or appearance. The only determinand which was found to be in excess of the guideline values was iron. DWSNZ (Ministry of Health, 1995) gives a guideline value, for aesthetic significance, of iron as 0.2mg/l, while DWSNZ (Department of Health, 1984) gives a highest desirable level of manganese of 0.05mg/l. The samples which exceeded these values are shown below in Table 5.3.

Sample Site	Iron (mg/l) 0.2*	Manganese (mg/l) 0.05*
Site 5	1.4	0.48
Site 8	-	0.26
Site 9	0.3	-
Site 14	0.4	-
Site 16	0.8	-

* indicates guideline value.

Table 5.3. Values exceeding New Zealand drinking water guidelines for chemical determinants of aesthetic significance.





■ Sampled in October, 1994.

□ Sampled in February, 1995.

* Site not resampled.

(<u>NB</u> manganese was only tested for in the second round of sampling)

Figure 5.11. Chemical Determinands of Health Significance.

5.7 Hydrochemical Variations

AS such no obvious hydrochemical variations have been found to distinguish between the aquifers, other than the presence of microbiological contaminants and elevated nitrate levels, which are typical of Aquifer 1. However, microbiological contaminants cannot be used to differentiate between water samples as they are derived from point sources.

Brown and Taylor (1974) were able to differentiate between the aquifers using isotope analysis as discussed in section 4.4.1. Nitrate nitrogen levels obtained from this study were used to give a rough indication of rainfall recharge which was in general agreement with Brown and Taylor's (1974) isotope derived recharge sources. Elevated nitrate nitrogen levels due to the influence of rainfall infiltration recharge were typical of unconfined Aquifer 1. Sample sites 7 and 9 located in Aquifer 2, also had elevated nitrate-nitrogen levels suggesting a possible input from rainfall recharge. This would be consistent with leakage from Aquifer 1, and Brown and Taylor (1974) indicated that Aquifer 2 receives a component of recharge from Mt. Fyffe runoff and from rainfall infiltration on the upper Plains area.

The implications that sites 7, 8 and 9 within Aquifer 2 returned positive coliform counts could mean that; the aquifer is only semi confined in that locality and contaminated water from Aquifer 1 is leaking downwards into the semiconfined aquifer, this argument is supported by the results of the pump test on well O31/204 which indicate that Aquifer 2 in that locality is only semi-confined; or that the well is located not far from the up-gradient boundary of the confining layer and is receiving contaminated water from an unconfined region of the aquifer, this is also a likely argument. Alternatively, badly sealed well casings could be providing a passage for inter-aquifer leakage.

Unfortunately it has not proved possible to distinguish between Aquifer 1 and Aquifer 2 on a hydrochemical basis.

5.8 Synthesis.

Over all the quality of Kaikoura groundwater was acceptable for most applications, with the exception of a few sites which were unsuitable for the irrigation of sensitive crops, however the majority of Kaikoura irrigation is carried out on pastoral land and water from these sites would suffice for that application. With respect to the potability of the water samples, most sites complied with the New Zealand drinking water guidelines with no sites exceeding the health based standards for chemical determinands. A number of sites however, returned positive microbiological contamination results, these sites were predominantly from the unconfined aquifer, although three sites from the confined aquifer also tested positive.

Water chemistry data from the Kaikoura Plains show that while some evolutionary trends are apparent such as the cation replacement series and increasing magnesium to calcium ratios with increasing residence times within the aquifers, other general trends such as the Chebotarev geochemical sequence of anion replacement are not readily apparent. This may indicate that the Kaikoura Plains are not extensive enough, and groundwater residence times not long enough for groundwaters to become chemically mature, alternatively it could be that elevated bicarbonate levels due to the production of carbon dioxide within the aquifers is masking the effect of the Chebotarev sequence.

No evidence has been found to indicate the occurrence of saltwater incursion in coastal areas. However, unconfined aquifers in coastal areas may contain elevated chloride concentrations due to the leaching and transport of seaspray residue to groundwater by rainfall infiltration.

6. SUMMARY AND CONCLUSIONS

6.1 Objectives

The primary objective of this project has been to complete a detailed hydrogeological investigation of the Kaikoura Plains to a stage where a conceptual hydrogeological and water balance models could be developed. This involved the undertaking of geological and geophysical investigations combined with baseline monitoring to obtain a sufficient database from which to establish the conceptual models.

6.2 Summary of Investigations

6.2.1 Geological Setting

The Kaikoura Plains were formed by the deposition of fluvial sediments from the Kowhai and Hapuku River systems. Postglacial sea level rise resulted in the truncation of the Hapuku River fan, with subsequent longshore transport and deposition of this material forming a barrier bar southwards from the Hapuku River fan towards the Kaikoura Peninsula. This barrier bar effectively dammed drainage of the Plains behind it, with the consequent accumulation of swamp deposits and silts from ponded flood waters of the Kowhai River, and to a lesser extent the Mt. Fyffe streams.

Transient electromagnetic geophysical investigations have determined the depth to the hydrogeological basement at up to 170 metres below ground surface, indicating a substantial thickness of unexplored gravels. A prominent feature identified in the baserock topography is the presence of a basement low, inferred to be a buried river valley. It is within this buried valley that a large proportion of the Kaikoura groundwater resource is inferred to be stored.

6.2.2 Aquifer Systems

Three main aquifer systems have been identified within the alluvial deposits of the Kaikoura Plains, consisting of one unconfined aquifer and two confined aquifers. Aquifers were identified in well logs as layers of predominantly coarse grained sediments separated by layers of predominantly fine grained sediments. Aquifer 1 is an unconfined aquifer covering most of the Kaikoura Plains area. Alluvial deposits forming Aquifer 1 vary in age from Last Glaciation, on the fans of the Hapuku River and the Mt. Fyffe streams, to recent flood deposits on the fan of the Kowhai River. Aquifer 2 is a semi-confined to confined aquifer underlying Aquifer 1, existing beneath the Kaikoura Plains from the Hapuku River fan to the Kahutara Hills, and possibly extends beneath the Hapuku River fan as well. It consists of Otiran Glacial age fluvial deposits and is separated from Aquifer 1 by a layer of predominantly fine grained postglacial deposits. Aquifer 3 is also confined and is separated from Aquifer 2 by a layer of predominantly fine grained sediments similar to that between Aquifers 1 and 2. Aquifer 3 is assumed to be of last interglacial age, and is thought to be confined within a buried baserock valley identified by the geophysical surveys.

Pump test data on the Kaikoura Plains is very limited, with only Aquifer 2 having been pump-tested. Values for aquifer transmissivity range from 0.043 to 2.47 m^3/min/m, and show a general indication of decreasing transmissivity towards the coast, especially in the lower plains area.

Groundwater flow directions for both Aquifers 1 and 2 are generally southerly to southeast, with an average hydraulic gradient of 12m/km for Aquifer 1 and 13m/km for Aquifer 2. There are however, deviations from the general trend resulting from localised aquifer input and output. Seasonal variations in groundwater levels range from less than one metre near the coast in Aquifer2 to 10+ metres in the recharge zones of both Aquifer 1 and 2 in the upper plains near the Kowhai River. Aquifer 2 also shows the influence of tidal fluctuations near the coast. No long term changes in aquifer storage have been indicated by long term variations in groundwater levels.

6.2.3 Water Balance

Natural recharge to the groundwater systems results from water leakage from the Kowhai River and the Mt. Fyffe streams and the infiltration of rainfall to groundwater. Groundwater recharge from river leakage is estimated from losses of surface flow measured by stream gauging, while groundwater recharge from rainfall is calculated from average annual rainfall totals and evaporation rates. Natural discharge of groundwater occurs as areas of seepage and springflow to streams and drains and also as outflow on the sea bed. Values for both aquifer inputs and outputs have a high degree of uncertainty, and the values obtained in this study should be treated cautiously as they are only an indication as to the order of magnitude of the input or output, rather than an exact figure. Inter-aquifer leakage is also expected to contribute significant recharge and discharge components for individual aquifers, however this is unable to be quantified. Water balances show that the Kaikoura groundwater system is in a state of equilibrium under both winter and summer conditions, where the total inputs to the groundwater system equal the total outputs. These balances do not take into account current rates of groundwater abstraction. It should be noted that the values given are best estimates and may be subject to large inaccuracies. The water balance for the Kaikoura groundwater system under winter equilibrium conditions is as follows:

Input Event	**l/s**	**Output Event**	**l/s**
Kowhai River Recharge	830	Spring Flow	960
Mt. Fyffe Streams Recharge	220	Throughflow	1865
Rainfall Recharge	1775		
Total Inputs	**2825**	**Total Outputs**	**2825**

6.2.4 Water Chemistry

Isotopic evidence suggests that recharge to Aquifer 1 is predominantly from rainfall on the lower plains, and a combination of rainfall and Mt. Fyffe drainage on the upper plains, with localised input from the Kowhai River. Aquifer 2 is predominantly recharged by leakage from the Kowhai River on the upper Kowhai fan area, with input from the Mt. Fyffe streams and rainfall infiltration in the region of the Mt. Fyffe fans. There is no isotopic data for Aquifer 3.

Groundwater sampled for water quality analysis was generally suitable for both drinking and irrigation purposes, however results indicated that the unconfined aquifer is very susceptible to microbiological contamination. No distinct chemical fingerprints were identified to distinguish between aquifers, although nitrate levels were consistent with isotopic analyses from the viewpoint of indicating recharge from local precipitation. Both Aquifers 1 and 2 displayed increasing ion concentrations with distance from recharge areas which may be used tentatively to indicate relative ages of groundwater. No evidence of saltwater incursion into aquifers near the coast was found.

6.3 Principal Conclusions

The Kaikoura groundwater system consists of one unconfined aquifer (Aquifer1) and two confined aquifers (Aquifers 1 and 2), with only the unconfined and upper confined aquifers being utilized.

The water balance of the Kaikoura groundwater system is in a state of equilibrium under both winter and summer conditions, indicating that a substantial groundwater resource is available for exploitation.

The water balance for the Kaikoura groundwater system presented here provides a basis for numerical modelling and future management of the groundwater resource of the Kaikoura Plains.

6.4 Recommendations

In order to gain a more complete understanding of the groundwater system of the Kaikoura Plains, the writer suggests that the following work be undertaken:

1. Continued baseline monitoring of the groundwater system, including the monitoring of groundwater fluctuations, rainfall measurement, streamgauging, pump-testing, piezometric surveys and water chemistry surveys in order to increase the database for the Kaikoura groundwater system, thus allowing more quantitative and definitive conclusions to be drawn.

2. Further geophysical work is required in order to obtain better control on the interpretation of depths to baserock and baserock topography. An extension of survey line B along Mt. Fyffe Road to the base of Mt. Fyffe would be very useful to this effect.

3. The drilling of an exploratory bore in a location which penetrates the buried valley identified in the geophysical surveys in order to properly calibrate the geophysical interpretations, and to evaluate the groundwater resource of these deeper and unexplored gravels.

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APPENDIX I: Soils.

I-I: INTRODUCTION

The soils of the Kaikoura Plains were classified using the field classification for soils as outlined by Taylor and Pohlen (1979). The field classifications for soils present on the Kaikoura Plains are outlined in Tables I-I and I-II below.

Soil Type	**Average Composition**				**Comments**
	Clay	**Silt**	**Sand**	**Gravel**	
Clay Loam	35%	30%	35%	-	Distinctly sticky when sufficiently moist, but presence of sand fraction can still be detected with care.
Silt Loam	23%	40%	37%	-	Fractions blended to give moderate plasticity without being very sticky, smooth soapy feel of silt is the main texture.
Sandy Loam	15%	15%	70%	-	Sand fraction quite obvious but will still mould readily when sufficiently moist without sticking appeciably to fingers.
Gravelly Sand	-	-	>70 %	7-30%	Mostly coarse and fine sand, containing so little clay that are loose when dry and not sticky when wet.
Stony Gravels					Predominantly gravel with up to 30% stones

Table I-I. Field classification for soils.
(Taylor and Pohlen, 1979).

	Clay	Silt	Sand	Gravel	Stones
Grainsize Classification	< 0.002mm	0.002-0.02mm	0.02-2.0mm	6.25-18.75mm	18.75-200mm

Table I-II. Grainsize Classifcation for field classification of soils (Taylor and Pohlen, 1979).

I-II: AVAILABLE SOIL WATER CAPACITY.

The available soil water capacity (AWC) was estimated for the different soil types present on the Kaikoura Plains using the following classification system (Table I-III) used by the North Canterbury Catchment Board (NCCB, 1983) for the central Canterbury Plains area.

Soil Type	**Availble Water Holding Capacity**
Deep soils (> 450mm)	> 100mm
Shallow soils (200-450mm)	60-100mm
Shallow and stony soils	40-80mm
Stony and shallow soils	30-60mm
Stony and very stony soils	< 30mm
Dominantly poorly drained soils	> 100mm
Soils with a humid climate	60-100mm
Sands	

Table I-III. AWC classification.

APPENDIX II: Lithological Classification.

The surficial Quaternary geology of the Kaikoura Plains was mapped by the author using the engineering geological field description for soil material described by Bell and Pettinga (1983), which is given in Table II-I.

The area was mapped over approximately two weeks in November, 1994. Field mapping was carried out on aerial photograph mosaics at a scale of 1:12500 using exposure in; road cuttings, drains, stream beds and banks, and on occasion shallow hand excavated trenches. Units were only mapped where they were in excess of one meter in thickness.

Field mapping techniques were aided be the use of aerial photograph interpretation and comparison with field soil maps provided, and mapped, by Alastair Wright of the Kaikoura office of the CRC.

Data acquired in the field was subsequently transferred to a 1:25000 scale base map drawn from an enlarged NZMS 260, Sheet O31. The final draft at this scale was then digitised and cleaned up using the CRC's Arc-Info and Arc-View GIS software.

TABLE II-1.

ENGINEERING GEOLOGICAL FIELD DESCRIPTION FOR SOIL MATERIAL

WEATHERING

	TERM	GRADE	SOIL DESCRIPTION
5	Completely Weathered (CW)	V	completely discoloured and altered, no trace of original fabric
4	Highly Weathered (HW)	IV	mostly altered and weakened, little trace of original fabric
3	Moderately Weathered (MW)	III	large discoloured portions of original soil separated by more altered material, significantly weakened
2	Slightly Weathered (SW)	II	minor discolouration of some parts of the original soil, no loss of strength
1	Unweathered (UW)	I	original soil with NO discolouration, loss of strength or other effects due to weathering
0	NOTE *		in coarse-grained soils record weathering grade of DOMINANT fraction here and qualify weathering grade of subordinate and/or minor fractions if appropriate

STRENGTH

	TERM	FIELD CRITERIA
1	loose	can be removed from exposure in disaggregated form by hand
2	compact	only removed from exposure by implement; material readily disaggregated by physical means
3	cemented +	only removed from exposure by implement; material does not disaggregate
4	hard	may be removed from exposure with difficulty by implement or hand, softened on immersion in water and may be remoulded
5	stiff	indented by thumb pressure, but not moulded by fingers; softened on immersion in water, and may be remoulded
6	firm	moulded or indented only by strong finger pressure, easily moulded after immersion in water
7	soft	easily indented or moulded by finger pressure
8	very soft	exudes between fingers when squeezed
9	spongy	readily compressed by finger pressure, but cannot be remoulded

+ may require description as rock material

UNIFIED SOIL CLASSIFICATION SYSTEM

FIELD IDENTIFICATION						GROUP SYMBOL	TYPICAL NAMES
COARSE-GRAINED SOILS	GRAVELS (<50% larger than 2mm)	clean gravels	wide range in grain size and substantial amounts of all interm sizes			GW	well graded GRAVELS
			predom. one size or a range of sizes with some interm sizes missing			GP	poorly graded GRAVELS
		gravels with fines	non-plastic fines (see ML below)			GM	poorly graded SILTY-GRAVELS
			plastic fines (see CL below)			GC	poorly graded CLAYEY-GRAVELS
	SANDS (<50% smaller than 2mm)	clean sands	wide range in grain sizes and substantial amounts of all interm. sizes			SW	well graded SANDS
			predom. one size or a range of sizes with some interm. sizes missing			SP	poorly graded SANDS
		sands with fines	non-plastic fines (see ML below)			SM	poorly graded SILTY - SANDS
			plastic fines (see CL below)			SC	poorly graded CLAYEY-SANDS
FINE-GRAINED SOIL	SILTS AND CLAYS	LIQUID LIMIT	SHINE	DILATANCY (1)	TOUGHNESS (1)		
		<50	none to very dull	quick to slow	none	ML	INORGANIC SILTS with slight plasticity
			moderate	none to very slow	medium	CL	INORGANIC CLAYS of low to medium plasticity
			none to very dull	slow	slight	OL	ORGANIC SILTS & CLAYS of low plasticity
		>50	dull	slow to none	slight to medium	MH	INORGANIC SILTS of high plasticity
			very glossy	none	high	CH	INORGANIC CLAYS of high plasticity
			moderate to v. glossy	none to very slow	slight to medium	OH	ORGANIC CLAYS of medium to high plasticity
HIGHLY ORGANIC SOILS			identified by colour, odour, spongy feel and fibrous texture			Pt	PEAT and other highly organic soils

PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS (1)

DILATANCY (reaction to shaking) -

1) Prepare pat of moist soil, adding water to make soft - but not sticky.

2) Place pat in palm of hand, shake horizontally by striking vigorously against other hand

Positive Reaction: appearance of water on surface of pat, which becomes glossy. When squeezed between fingers, water and gloss disappear, pat stiffens and may crumble

TOUGHNESS: (consistency near plastic limit) -

1) Mould sample to consistency of putty, adding water or air drying as required

2) Roll to thin (3mm) thread, fold and reroll repeatedly until thread crumbles at plastic limit

3) Knead together and continue until lump crumbles

Diagnosis: a tough thread and stiff lump indicate high plasticity; a weak thread and lump low plasticity clays

GROUP SYMBOL CODINGS FOR USCS

COLUMN 1		COLUMN 2	
G:1	C:4	W:1	C:4
S:2	O:5	P:2	L:5
M:3	Pt:6	M:3	H:6

BOUNDARY CLASSIFICATIONS specify, enter 0,0

WEATHERING TERM	WATER CONTENT TERM	STRENGTH TERM	COLOUR	FABRIC	SOIL NAME	USCS SYMBOL
--- ---	---	---	--- --- ---	---	--- --- ---	--- ---

WATER CONTENT

	TERM	FIELD CRITERIA
1	Dry	looks and feels dry; fine-grained soils usually hard, powdery or friable; coarse-grained soils may run freely through hands
2	Moist	soil feels cool and may be darkened in colour, particles tend to adhere in coarse-grained materials, fine-grained soils may be softened
3	Wet	soils feel cold and are darkened in colour, free water forms on hands when sample is disturbed
4	Saturated	restricted to wet soils below the water table or the static water level in excavations or drill holes

COLOUR

1: light	1 pinkish	1 pink
2: dark	2 reddish	2 red
	3 yellowish	3 yellow
	4 brownish	4 brown
	5 olive	5 olive
	6 greenish	6 green
	7 bluish	7 blue
	8 whitish	8 white
	9 greyish	9 grey
		0 black

FABRIC

1: finely layered (< 25 mm)
2: coarsely layered (25-100 mm)
3: massive
4: other (specify)

* SUBORDINATE FRACTION
20-50% volume visual estimate

1 coarse	gravelly
2 medium	
3 fine	
4 coarse	sandy
5 medium	
6 fine	
7 silty	
8 clayey	
9 peaty	

DOMINANT FRACTION
>50% volume visual estimate

PARTICLE SIZE

SOIL TYPE TERM		PARTICLE SIZE (mm)	GRAPHIC LOG
1 coarse	gravel	> 60	
2 medium		20-60	
3 fine		2-20	
4 coarse	sand	0.6-2.0	
5 medium		0.2-0.6	
6 fine		0.06-0.2	
7 silt		0.002-0.06	
8 clay		< 0.002	
9 peat		NA	

* MINOR FRACTION
< 20% volume visual estimate

WITH SOME	1 coarse	gravel
	2 medium	
	3 fine	
	4 coarse	sand
	5 medium	
	6 fine	
	7 silt	
	8 clay	
	9 peat	

APPENDIX III : Selected Radiocarbon dates

Source: Van Dissen & Brown, 1995

Age[+]	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
Cretaceous (Haumarian)		O31/f255	Middle Creek, Mt Fyffe	O31/610745			Carbonaceous mudstone	Assemblage - Marine and terrestrial palynomorphs, dominated by bisaccate podocarps - *Podocarpidites, Phyllocladidites mawsonii, Microcachryidites antarcticus*, etc. Key taxa - *Proteacidites granoratus* (Couper) *Triorites subalveolatus* (Couper) *Nothofagidites kaitangataensis* (Te Punga) *Ornamentifera sentosa* Dettmann & Playford. DCM
Early Tertiary, Dannevirke (Teurian - Heretaungan)		O31/f251	Mt Fyffe	O31/617747			Limestone (Amuri Limestone)	Contains scattered planktic foraminifera and radiolaria. Age assigned on presence of *Morozovella* sp CPS
Early Tertiary, Dannevirke (Teurian - Heretaungan)		O31/f252	Middle Creek, Mt Fyffe	O31/610745			Limestone (Amuri limestone)	As for O31/f251
Early Tertiary, Dannevirke (Teurian - Heretaungan)		O31/f256	Land slide, Mt Fyffe	O31/609737			Limestone (Amuri limestone)	As for O31/f251
>50 000	A1566	O31/f167	O31/w156, Hawthorne Rd, Kaikoura	O31/657684	33	-27	Wood fragments	
>48 000	A1552	O31/f164	O31/w156, Hawthorne Rd Kaikoura	O31/657684	17	-12	Shells	*Nucula nitidula* A. Adams *Chlamys gemmulata* (Reeve) *Barbatia novaezelandiae* (Smith) *Modiolus* sp. *Tawera spissa* (Deshayes) ?Mactridae ?*Cookia sulcata* (Gmelin)

Age+	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
								Trochus viridis Gmelin *Diloma bicanaliculata* (Dunker) *Antisolarium egenum* (Gould) *Stiracolpus delli* (Marwick) *Maoricolpus roseus* (Quoy & Gaimard) ?*Cominella* sp. *Xymene ? aucklandica* (Hutton) *Dentalium* sp. *Rhyssoplax aerea* (Reeve) *Terebratella inconspicua* A fauna typical of that at 5-10 m offshore from Kaikoura today - shallow water with a soft bottom (sand or muddy sand) off an exposed rocky shore. AGB.
>45 000	A1544	O31/f172	O31/w156, Hawthorne Rd, Kaikoura	O31/657684	40.0	-35.0	Shells	Bryozoa - Few unidentified fragments Arthropoda, Cirripedia - Unidentified small barnacle plates Brachiopoda - *Terebratella inconspicua* *Tegulirhynchia nigricans* Echinoidea *Evechinus chloroticus* ("kina"). Arthropoda, Macrura - Small "fingers" of crab chelae Mollusca - Polyplacophora: ?*Leptochiton inquinatus* (Reeve) *Rhyssoplax aerea* (Reeve) Gastropoda: ?*Cellana* sp. *Emarginula striatula* (Quoy & Gaimard) ?*Haliotis* sp. *Zethalia zelandica* (Hombron & Jacquinot)

Age*	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
								Trochus tiaratus (Quoy & Gaimard)
								Trochus viridis Gmelin
								Diloma sp.
								Cavodiloma coracina (Philippi)
								?*Calliostoma* sp.
								Pisinna zosterophila (Hutton)
								Rissoina sp.
								Sigapatella novaezelandiae (Lesson)
								Maoricolpus roseus (Quoy & Gaimard)
								Zeacolpus vittatus (Hutton)
								Stiracolpus aff. *delli* (Marwick)
								Crepidula monoxyla (Lesson)
								Zemitrella sulcata (Hutton)
								Zemitrella choava (Reeve)
								Zymene traversi (Hutton)
								?*Cominella* sp.
								?*Buccinulum* sp.
								Austromitra sp.
								?*Liracraea* sp.
								Neoguraleus sp.
								Aoteadrillia wanganuiensis (Hutton)
								Pervicacia sp.
								?*Turbonilla* sp.
								Bivalvia : *Chlamys gemmulata* (Reeve)
								Chlamys zelandiae (Gray)
								Tiostrea chilensis lutaria (Hutton)
								Pododesmus (Monia) zelandica (Gray)
								?*Modiolus areolatus* (Gould)
								Verticipronus mytilus Hedley
								Borniola reniformis (Suter)
								Notolepton antipodum (Filhol)
								Mysella cf. *hounselli (Powell)*
								Mactridae indet.
								?*Zenatia* sp.
								Gari sp.

Age[1]	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
								Leptomya retiaria (Hutton) Tellinidae indet. *Pleuromeris* sp. *Cardita aoteana* Finlay *Tawera spissa* (Deshayes) *Dosina zelandica* Gray *Dosinia (Kereia) greyi* (Zittel) ?*Notirus* sp. Pholadidae indet. (*?Barnea similis Gray)* Paleoenvironment - This fauna is mainly from a sandy substrate in shallow water, near a subtidal rocky shore. AGB
> 39 900	6700	O31/f168	O31/w156, Hawthorne Rd, Kaikoura	O31/657684	36	-30	Shells	Bivalvia - *Tiostrea chilensis lutaria* (Hutton) *Mytilus edulis aoteanus* (Powell) *Chlamys gemmulata* (Reeve) *Tawera* sp. *Dosinia (Austrodosinia) anus* (Philippi) *Arcopagia disculus* (Deshayes) Gastropoda - Trochidae indet. Turbinidae indet. *Xymene aucklandica* (Hutton) *Aoteadrillia wanganuiensis* (Hutton) Paleoenvironment - If all lived at the deposition site, this assemblage would suggest deposition in an open marine environment in several (about 10-20) metres of water off a sandy beach, near a rocky shore. The abraded state of many of the shells suggest transportation, possibly to shallow water near a beach. AGB

Age+	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
		O31/f169	O31/w156 Hawthorne Rd, Kaikoura	O31/657684	37.5	-31.5	Shells, wood fragments and seeds	Bryozoa - Unidentified fragments Arthropoda, Cirripedia - Unidentified small barnacle plates Brachiopoda - Small abraded fragments - indet. Echinoidea - *Evechinus chloroticus* ("kina") fragments Spatangoida or similar Arthropoda, *Macrura* - Small "fingers" of crab chelae Polychaeta - Odd diverse worm tubes Mollusca - Polyplacophora : *Leptochiton inquinatus* (Reeve) *?Lorica* sp. *Rhyssoplax* sp. Gastropoda : *Notoacmea helmsi* (Smith) *Zethalia zelandica* (Hombron & Jacquinot) *Trochus tiaratus* (Quoy & Gaimard) *Diloma* sp. *Micrelenchus* sp. *Thoristella chathamensis* (Hutton) *Pisinna zosterophila* (Hutton) *Merelina* sp. *Rissoina* sp. *Sigapatella novaezelandiae* (Lesson) *?Stiracolpus* sp. *Zemitrella sulcata* (Hutton) *Zemitrella choava* (Reeve) *Xymene traversi* (Hutton) *Buccinulum sp.* *Austromitra* sp.

Age*	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
								?Liracraea sp. *?Neoguraleus* sp. *Aoteadrillia wanganuiensis* (Hutton) *Pervicacia* sp. *Chemnitzia* sp *?Turbonilla* sp. Bivalvia : *Nucula* sp. *Chlamys gemmulata* (Reeve) Ostreidae indet. *Pododesmus (Monia) zelandica* (Gray) *Verticipronus mytilus* (Hedley) *Melliteryx parva* (Deshayes) *Borniola reniformis* (Suter) *Mysella* cf. *hounselli* (Powell) *Notolepton antipodum* (Filhol) Mactridae indet. *Tawera spissa* (Deshayes) *Cardita* sp. *Zenatia acinaces* (Quoy & Gaimard) *?Notirus* sp. *Hiatella arctica* (Linné) *Pholadidea* sp. Paleoenvironment - This fauna is mainly epifaunal taxa from a shallow subtidal hard substrate, where most taxa lived on rocks or on the macroalagae attached to the rocks. A few molluscs were transported in from sand beaches or slightly further off-shore on soft substrata - these transported shells from other environments are much more broken and abraded than those from a hard substrate. This fauna might be expected at present not far below low tide on Kaikoura Peninsula. AGB.

Age*	NZ 14C No	NZ Fossil Record No	Locality	Grid Reference	Depth from surface (m)	Altitude with ref to MSL (m)	Sample	Fauna/Flora
2624 ± 88	7636	O31/f258	Land slide Mt Fyffe	O31/609737			Carbonaceous siltstone	Assemblage spores -44% *Dicksonia* sp. 17% *Cyathea* sp. Pollen - *Podocarpus* species (45%) Rimu (25%) Myrtaceae (7%) Fagaceae (6%) Grass (6%) Paleoenvironment - Accumulated during temperate climate. DCM
1724 ± 84	6890	O31/f165	O31/w156, Hawthorne Rd Kaikoura	O31/657684	18	-13	Wood	
		O31/f161	031/w156 Hawthorne Rd Kaikoura	O31/657684	14	-8	Wood and shell	Mollusca - indet. AGB
1698 ± 56	6645	O31/f95	Middle Creek, Mt Fyffe	O31/612724	1.5	90	Wood	*Podocarpus totara*. BPJM
1688 ± 56	6641	O31/f93	Middle Creek, Mt Fyffe	O31/612722	5	90	Wood	*Podocarpus totara*. BPJM
600 ± 52	6575	O31/f94	Middle Creek, Mt Fyffe	O31/615719	5	90	Wood	*Podocarpus totara*. BPJM
Modern	7635	O31/f250	Floodgate Creek, Mt Fyffe	O31/593718	1.0		Peat	Assemblage - 85% bracken *(P. escalentum)*. Pollen dominated by grasses (59%), rimu (6% *Dacrydium cupressinum)*, Compositae (6%). Contains apparently in situ *Taraxacum* and *Pinus*. Paleoenvironment - Damp, burnt-over fern land, probably post occupation. DCM

Fossil determinations - Identified by initials as listed:

A.G.Beu
D.C. Mildenhall
B.P.J. Molloy
C.P. Strong

*All radiocarbon dates are Conventional Radiocarbon Age as defined by Stuiver and Polach (1977) in years BP (1950 AD)

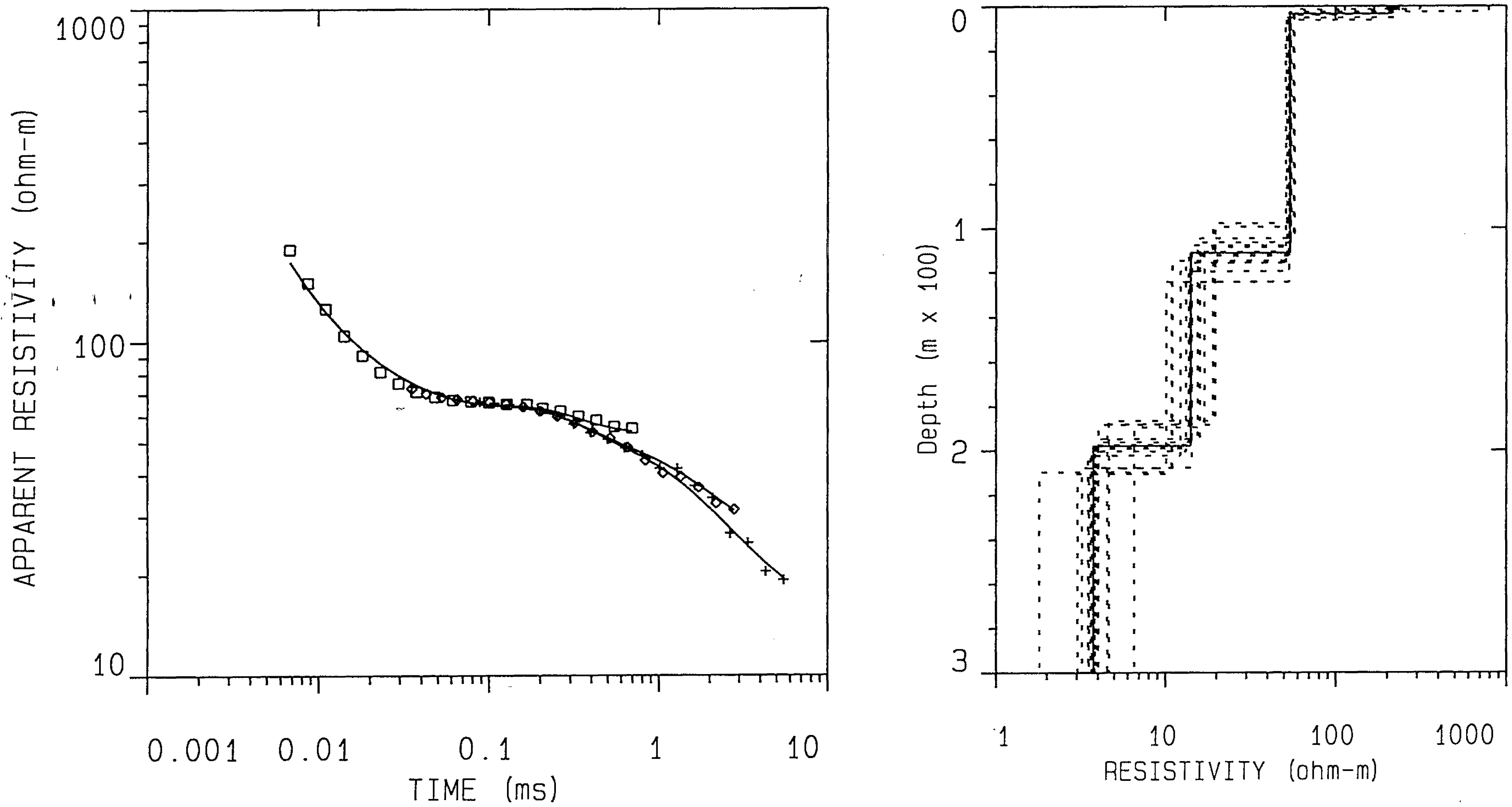
APPENDIX IV: Geophysics.

IV-I: SURVEY LINE A.

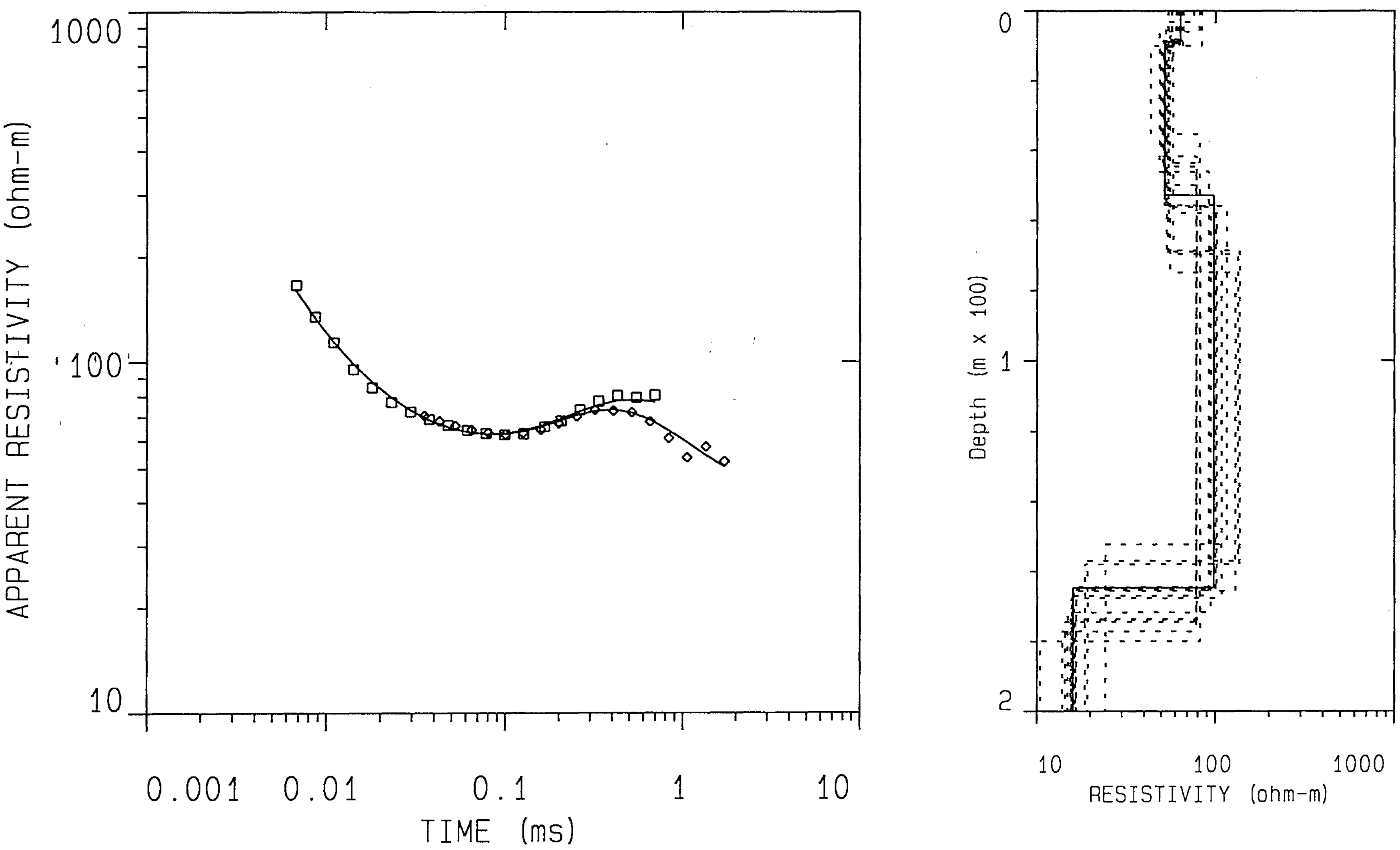
IV-I-I APPARENT RESISTIVITY CURVES AND EQUIVALENCE MODELS.

KAIK01	=	SOUNDING 1
KAIK02	=	SOUNDING 2
KAIK03	=	SOUNDING 3
KAIK04	=	SOUNDING 4
KAIK05	=	SOUNDING 5
KAIK06	=	SOUNDING 6
KAIK07	=	SOUNDING 7
KAIK08	=	SOUNDING 8
KAIK09	=	SOUNDING 9
KAIK10	=	SOUNDING 10
KAIK11	=	SOUNDING 11

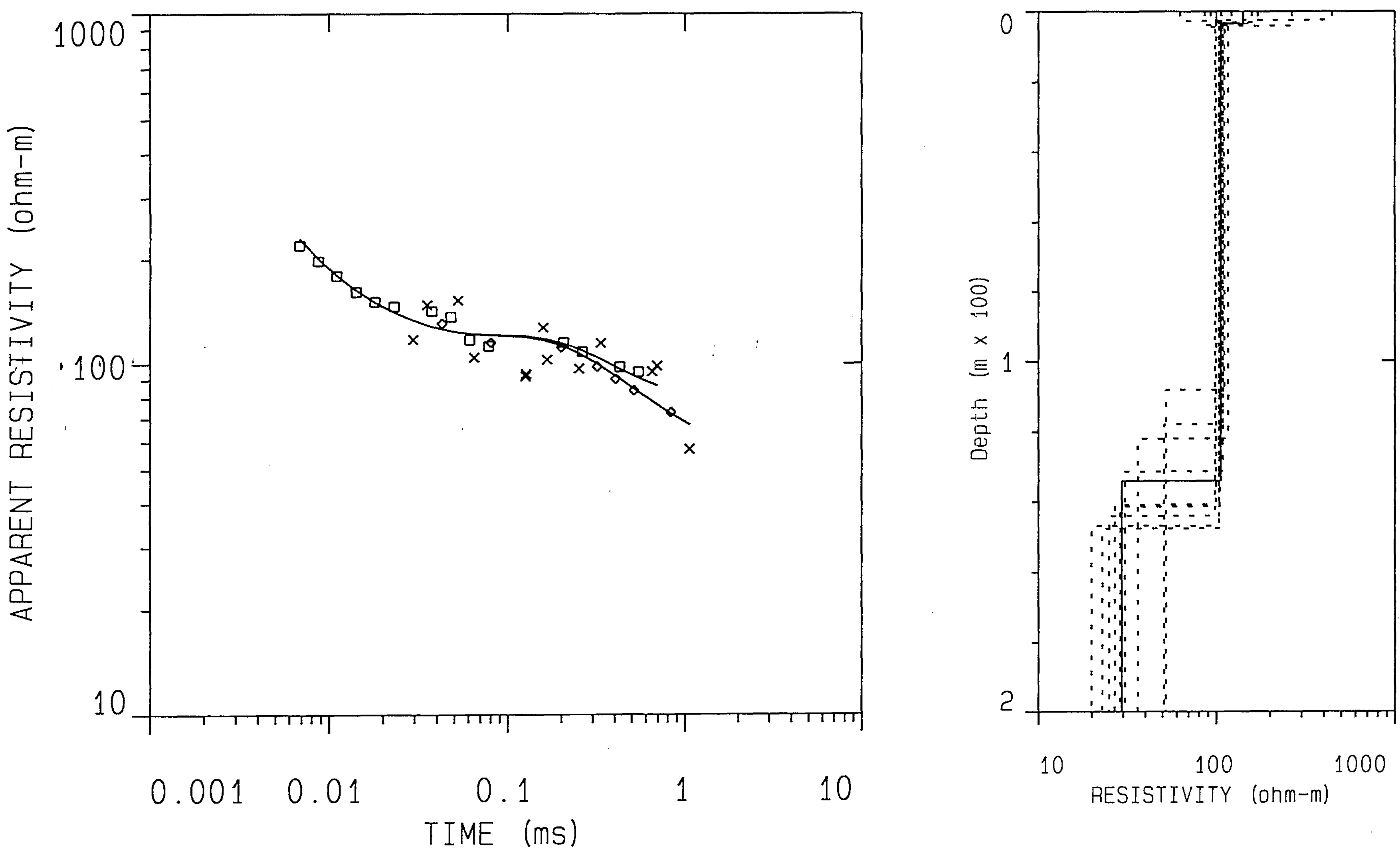
KAIK01


APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.001
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
3
1
10
100
1000
RESISTIVITY (ohm-m)

KAIKO2

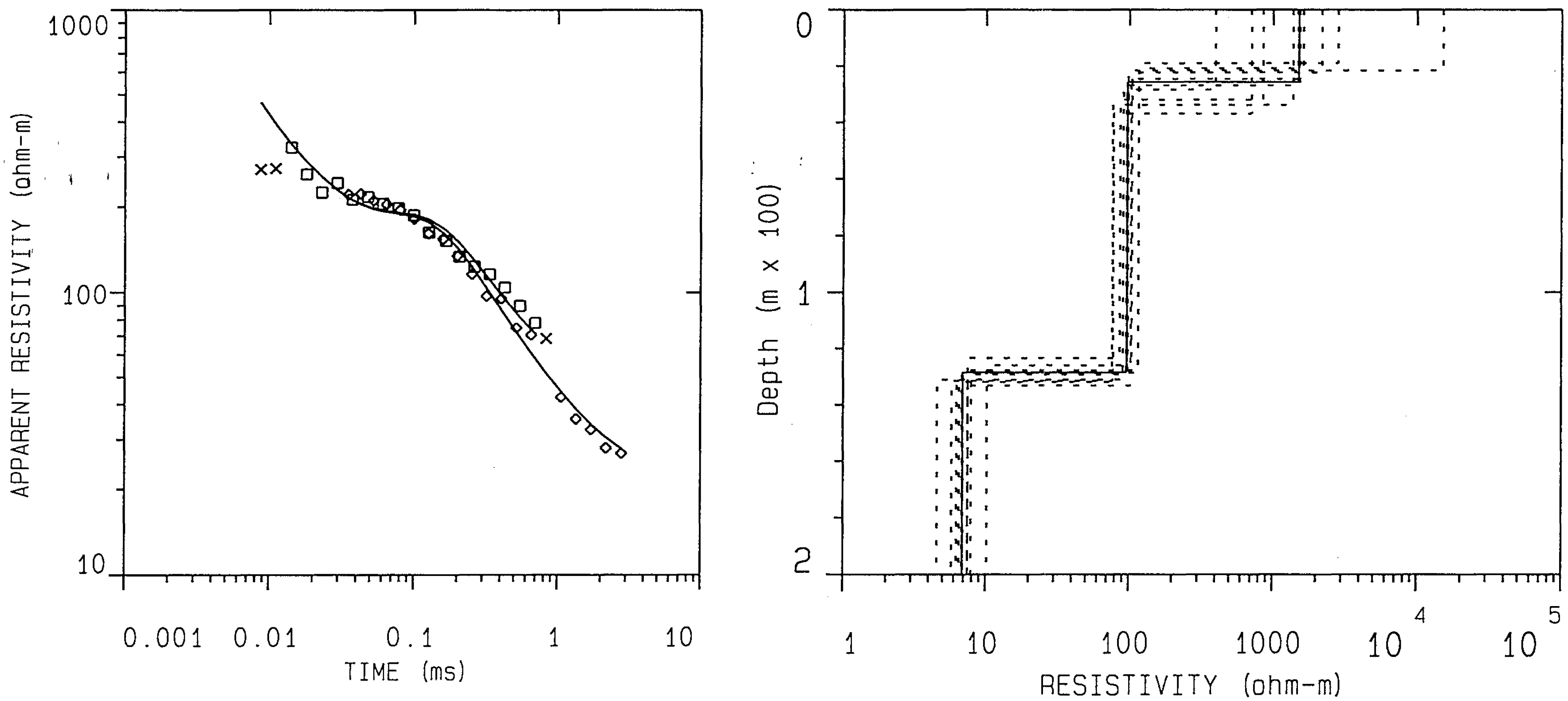

1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

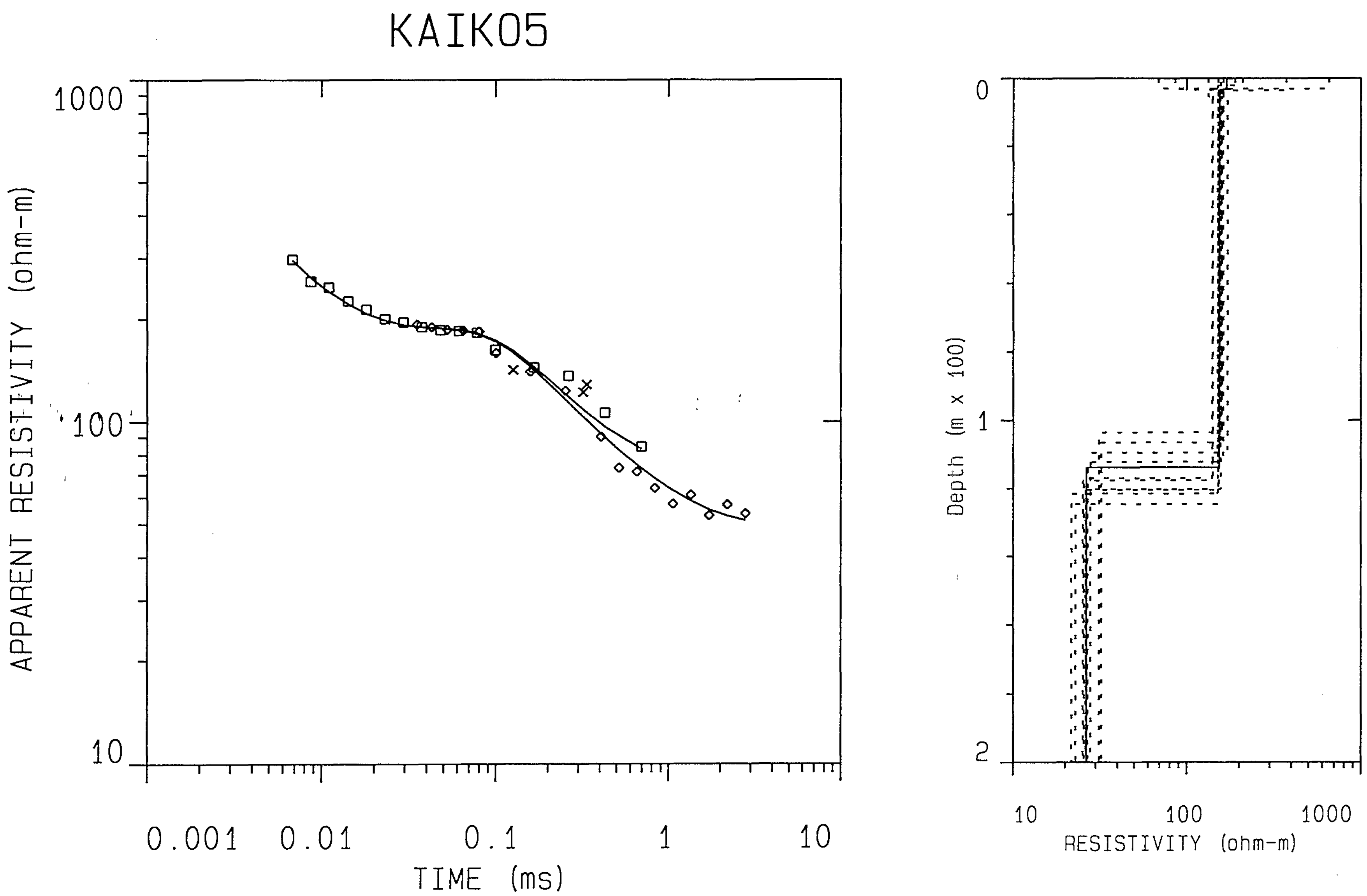
KAIK03



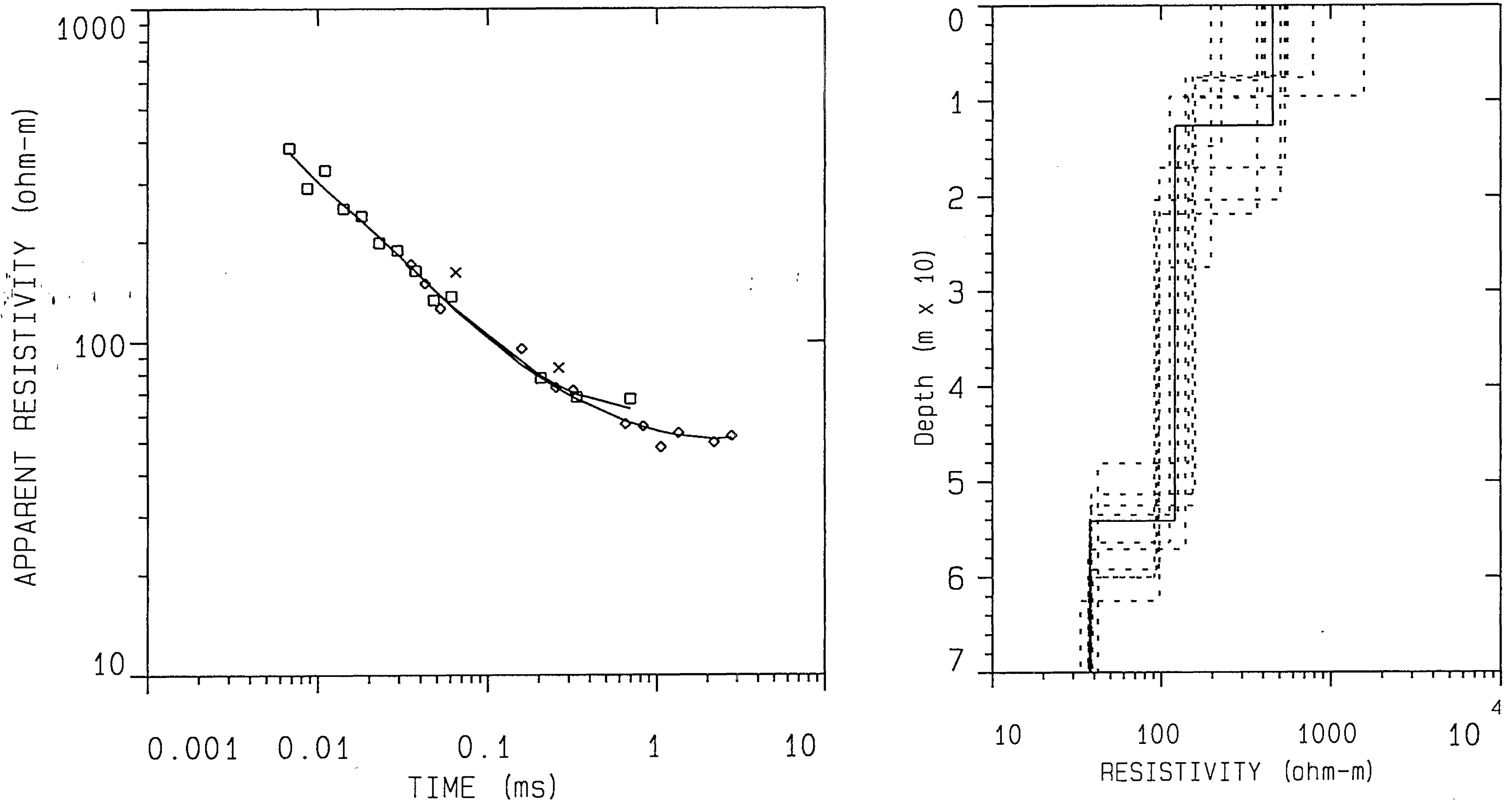
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

KAIK04


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001 0.01 0.1 1 10
TIME (ms)
0
1
2
Depth (m x 100)
1 10 100 1000 10^4 10^5
RESISTIVITY (ohm-m)

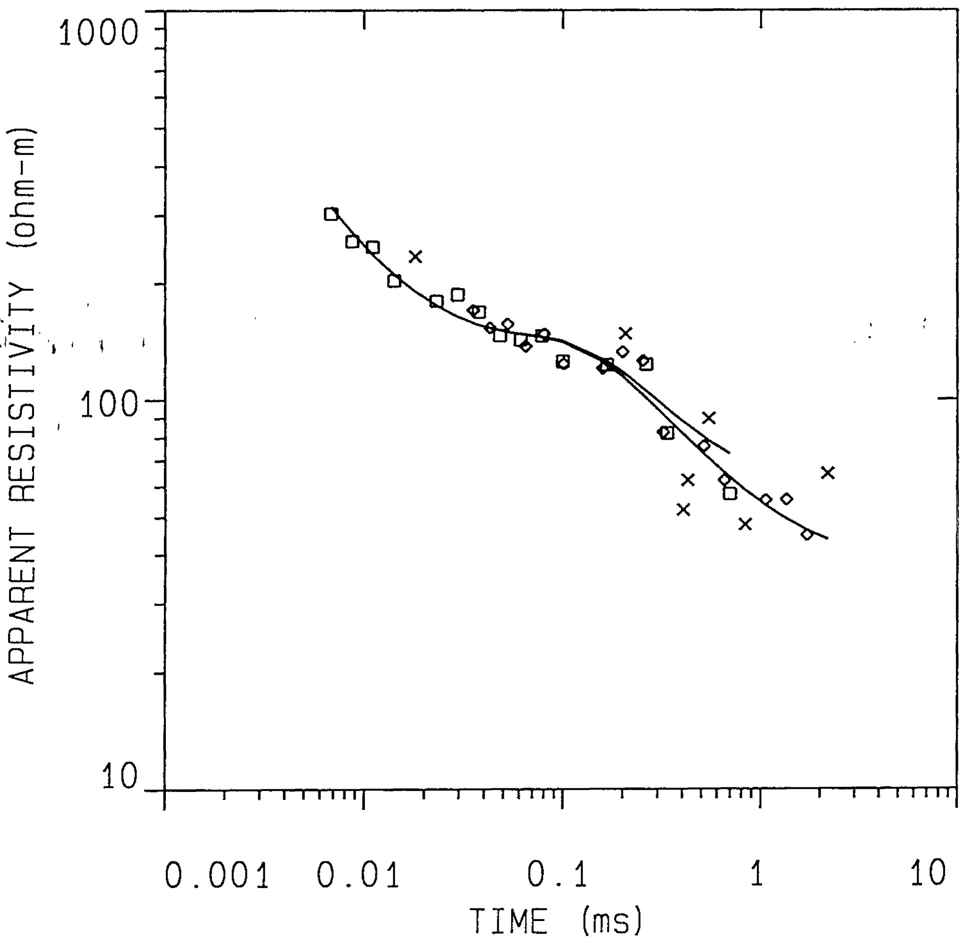

KAIK05
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

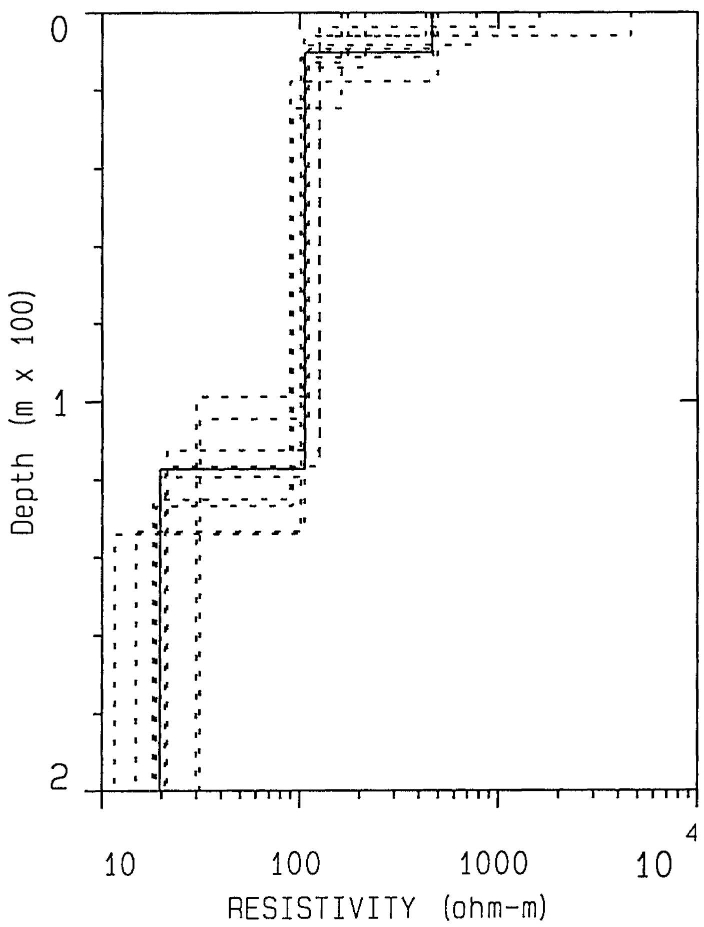
KAIK06



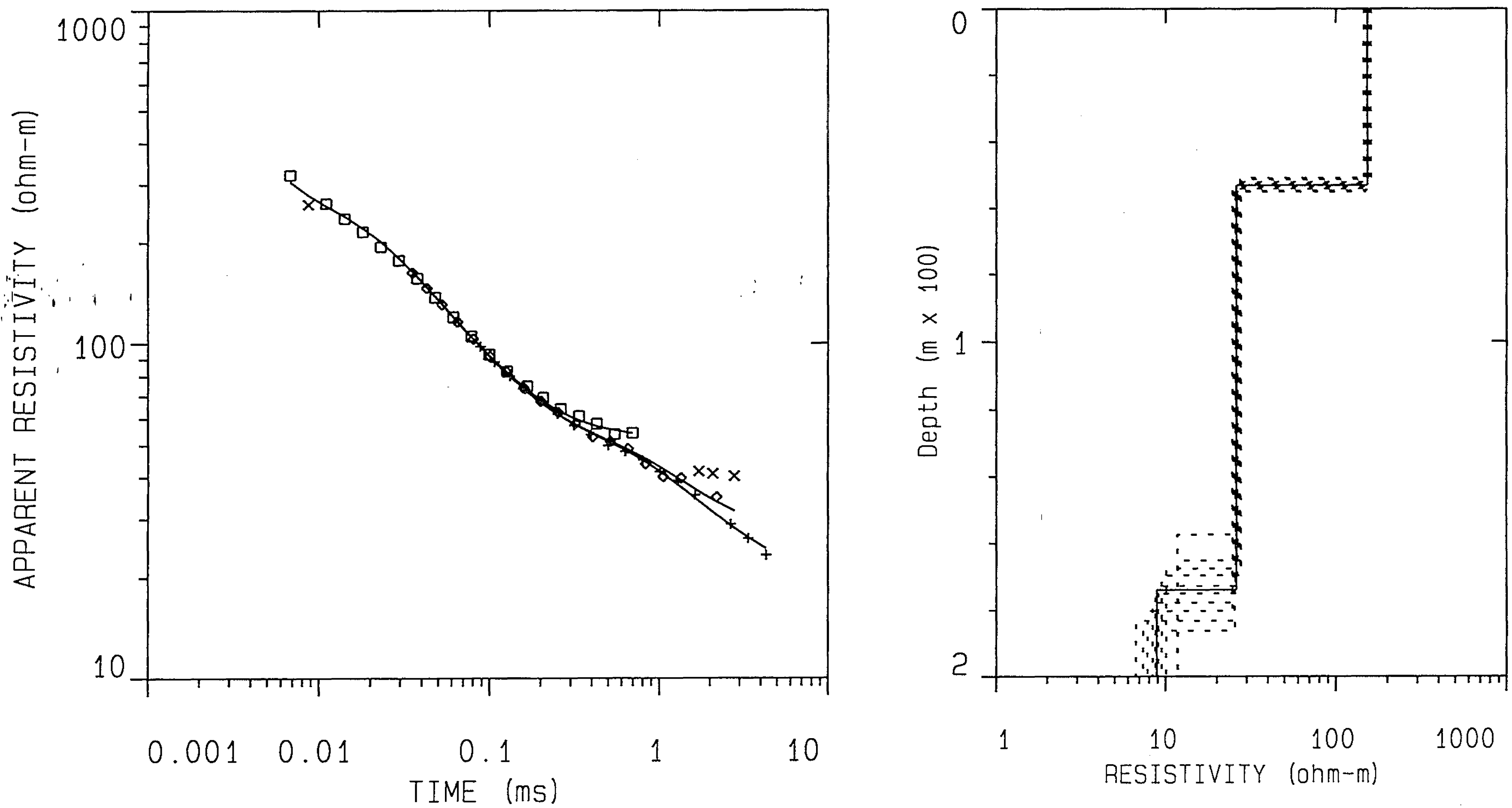
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
Depth (m x 10)
10
100
1000
10^4
RESISTIVITY (ohm-m)

KAIK07


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)

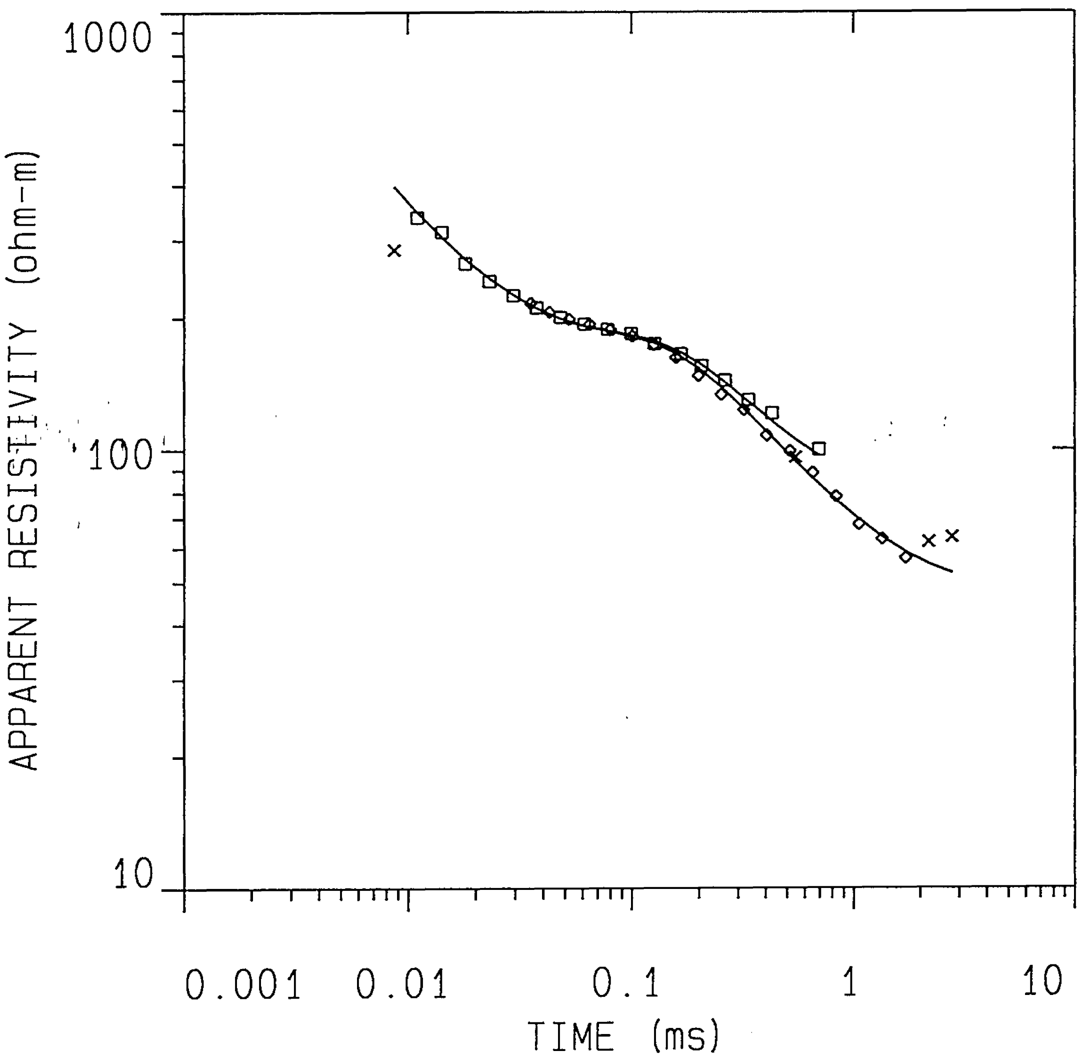

0
1
2
Depth (m x 100)
10
100
1000
10^4
RESISTIVITY (ohm-m)

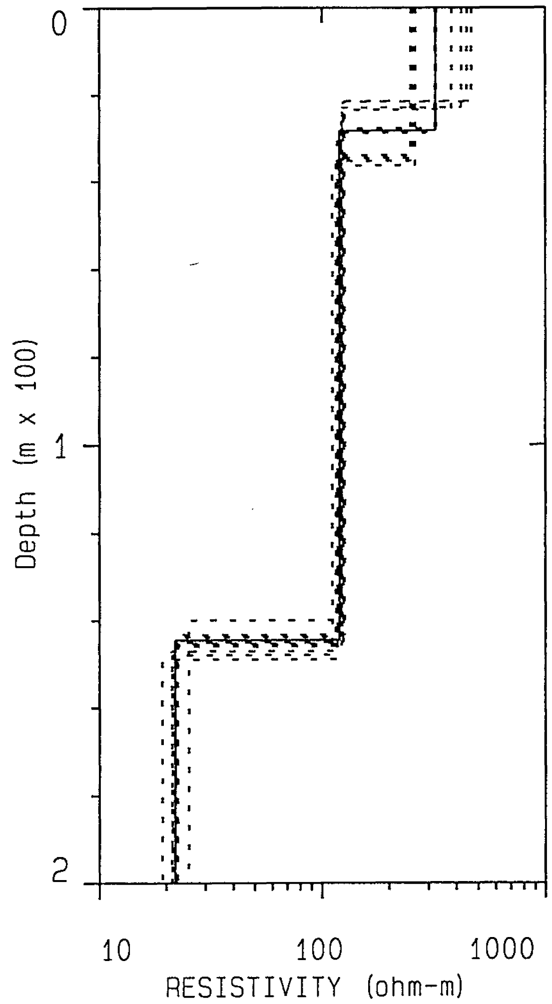
KAIK08



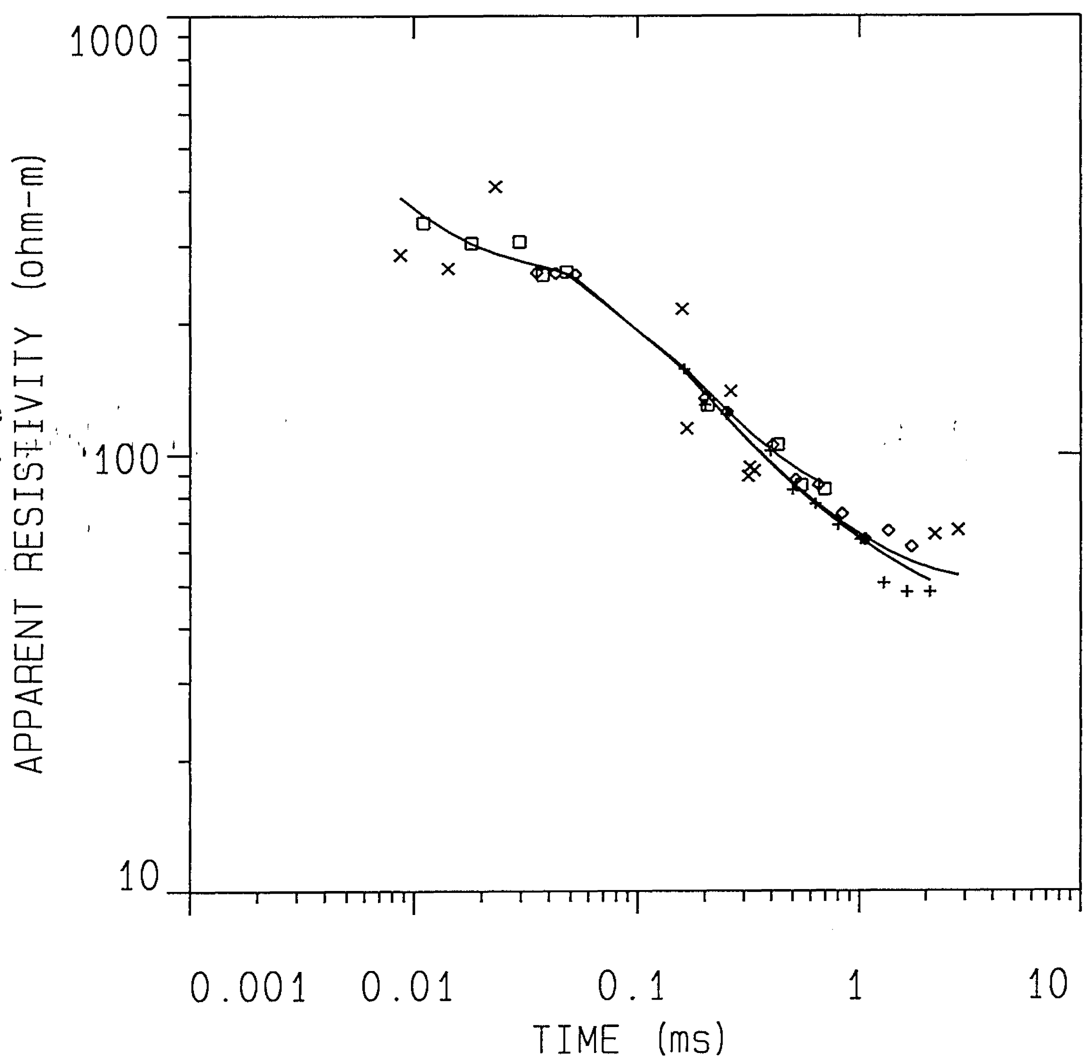
APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.001
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
1
10
100
1000
RESISTIVITY (ohm-m)

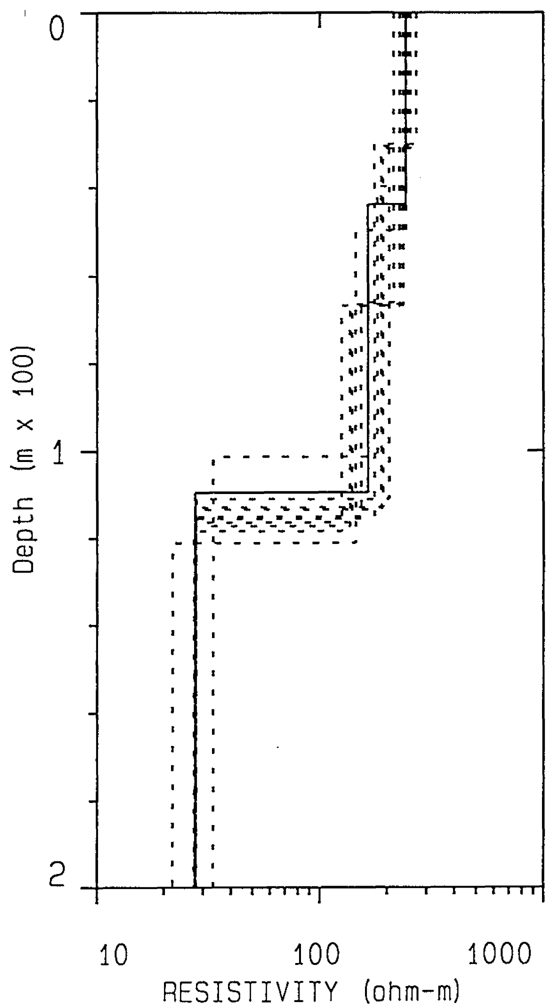
KAIK09


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)

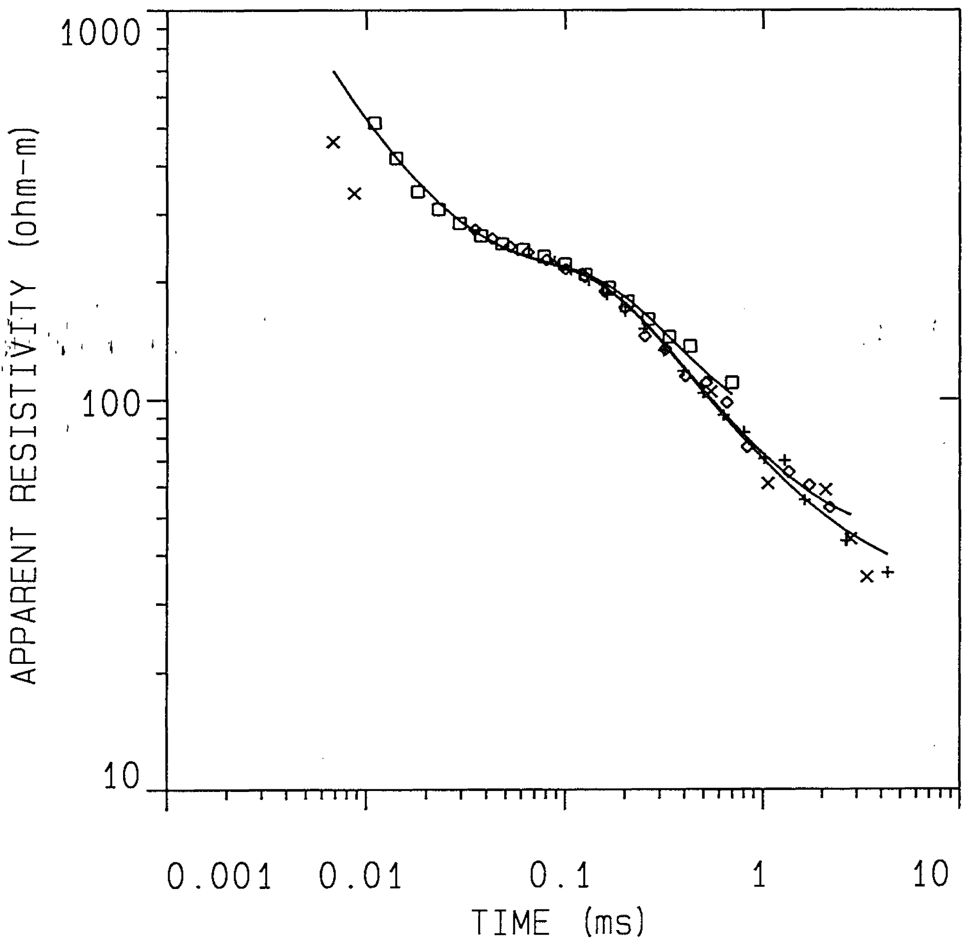

0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

KAIKO10

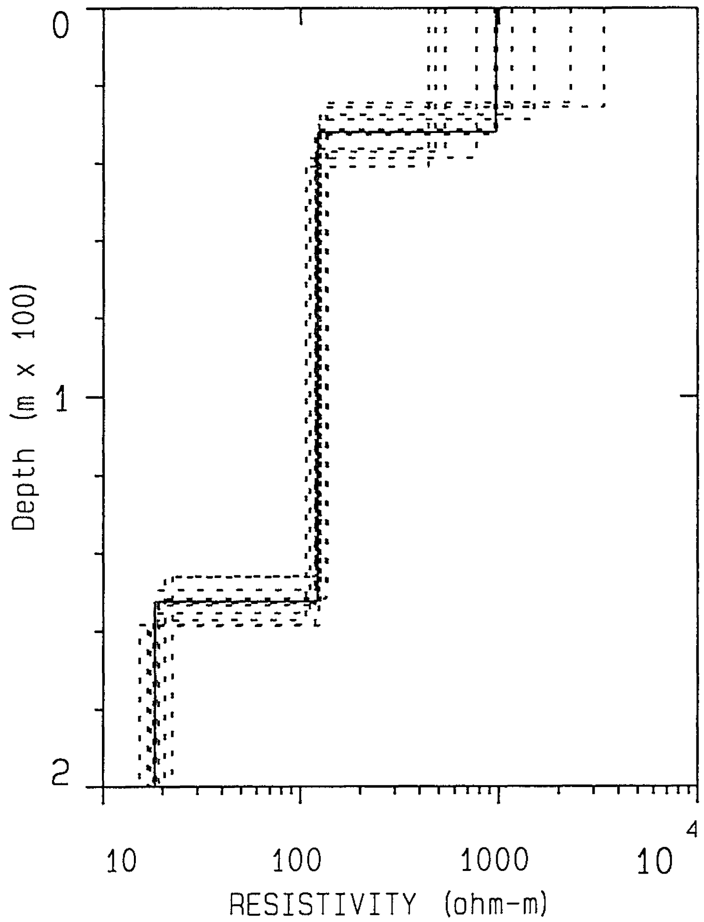

1000
100
10
0.001
0.01
0.1
1
10
TIME (ms)
APPARENT RESISTIVITY (ohm-m)


0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

KAIK011



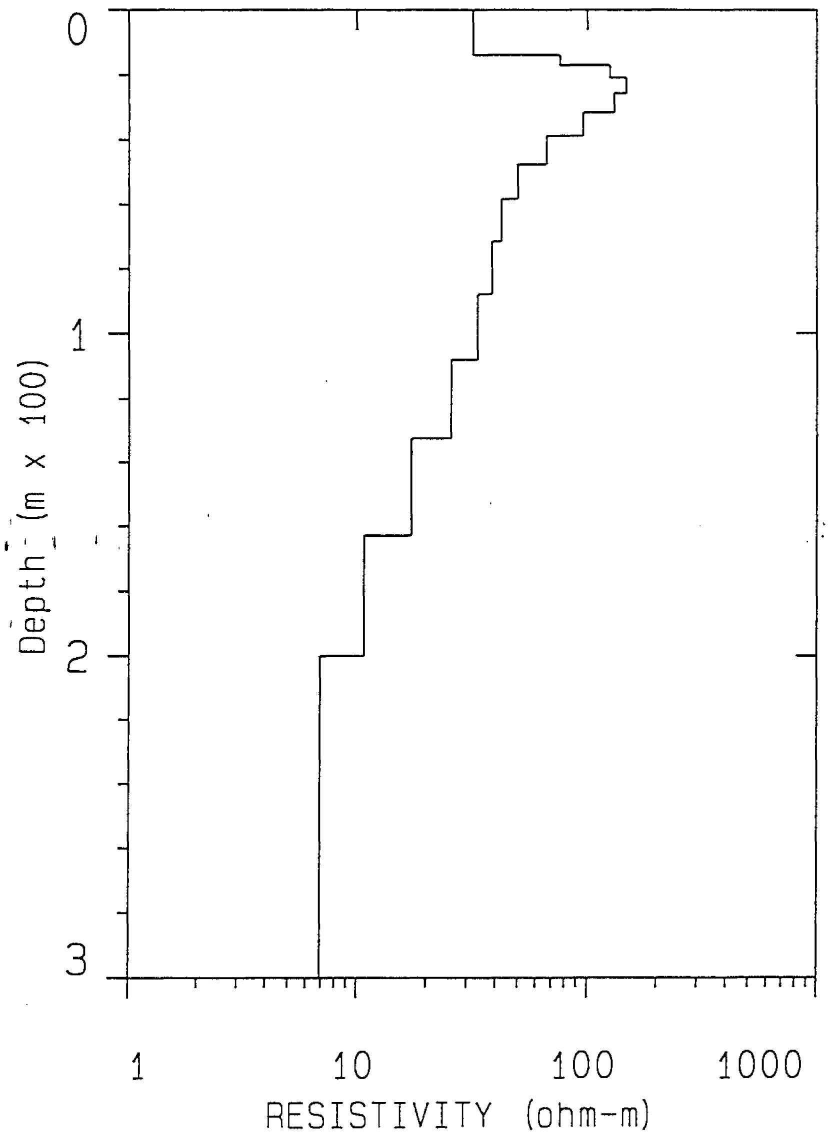
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)



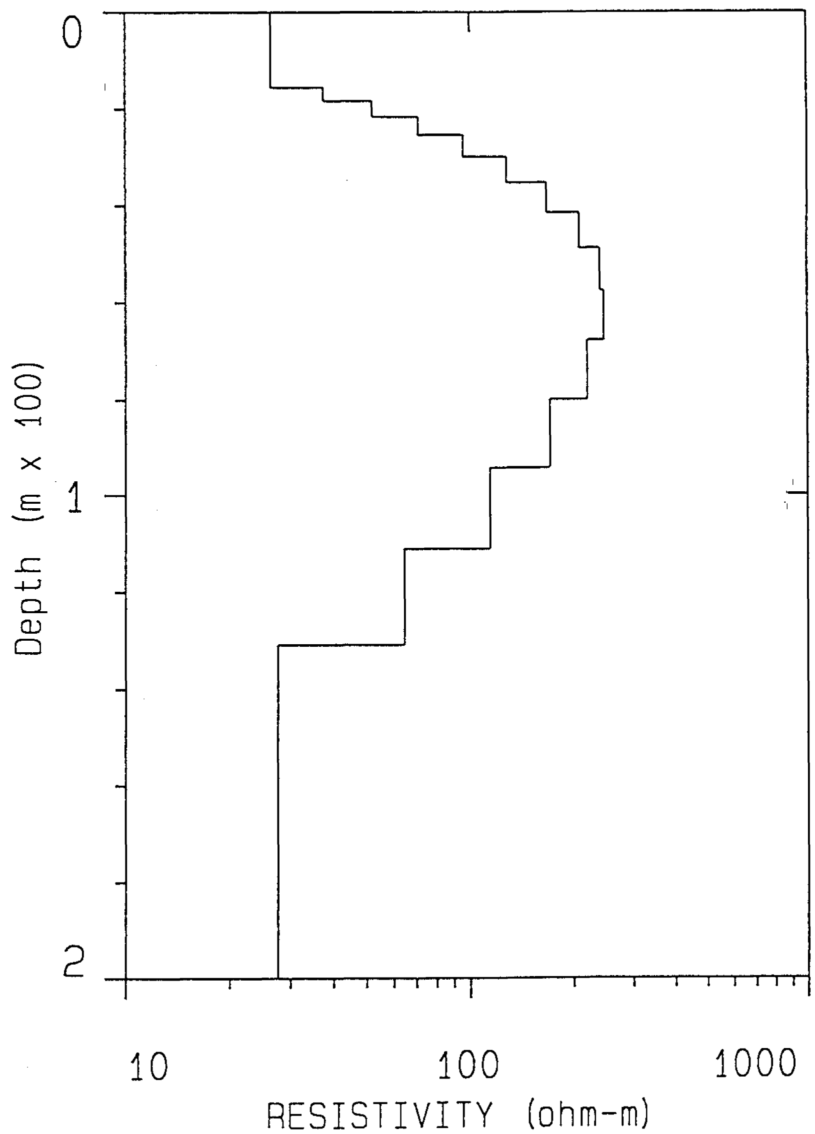
0
1
2
Depth (m x 100)
10
100
1000
10^4
RESISTIVITY (ohm-m)

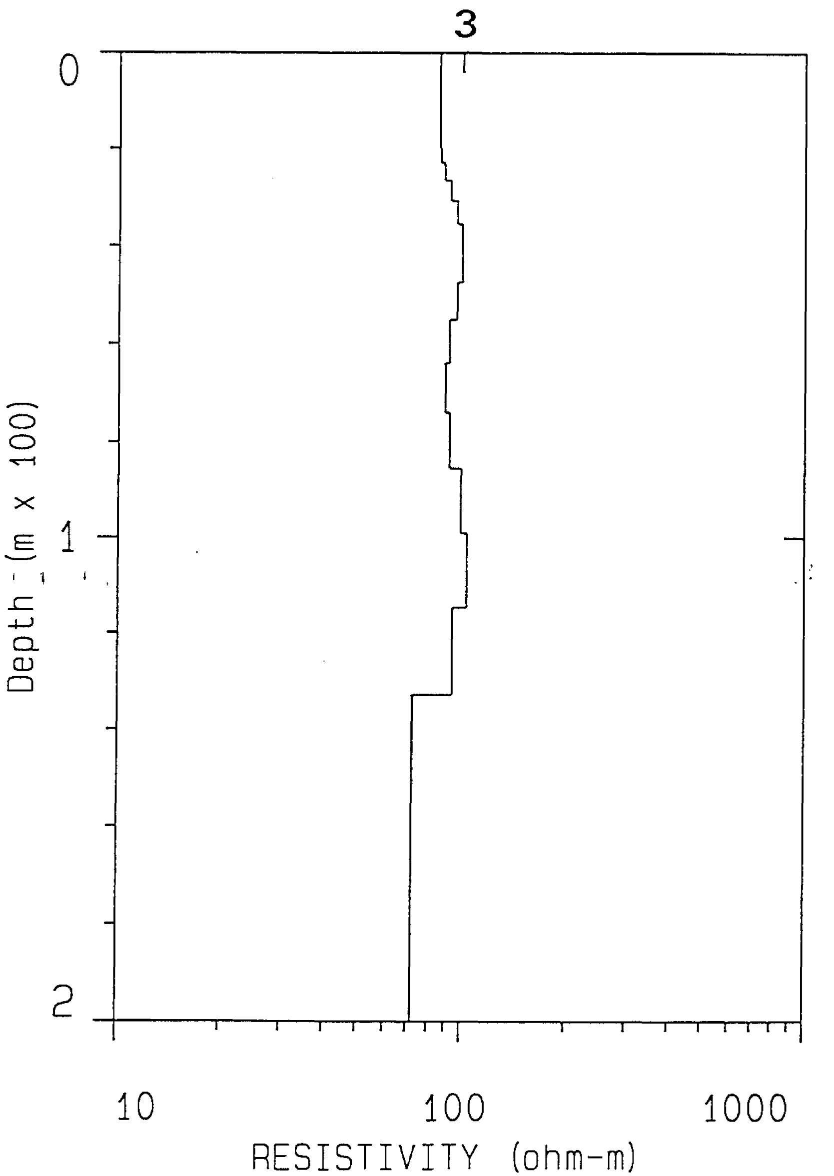
IV-I-II: SMOOTH MODELS.

1

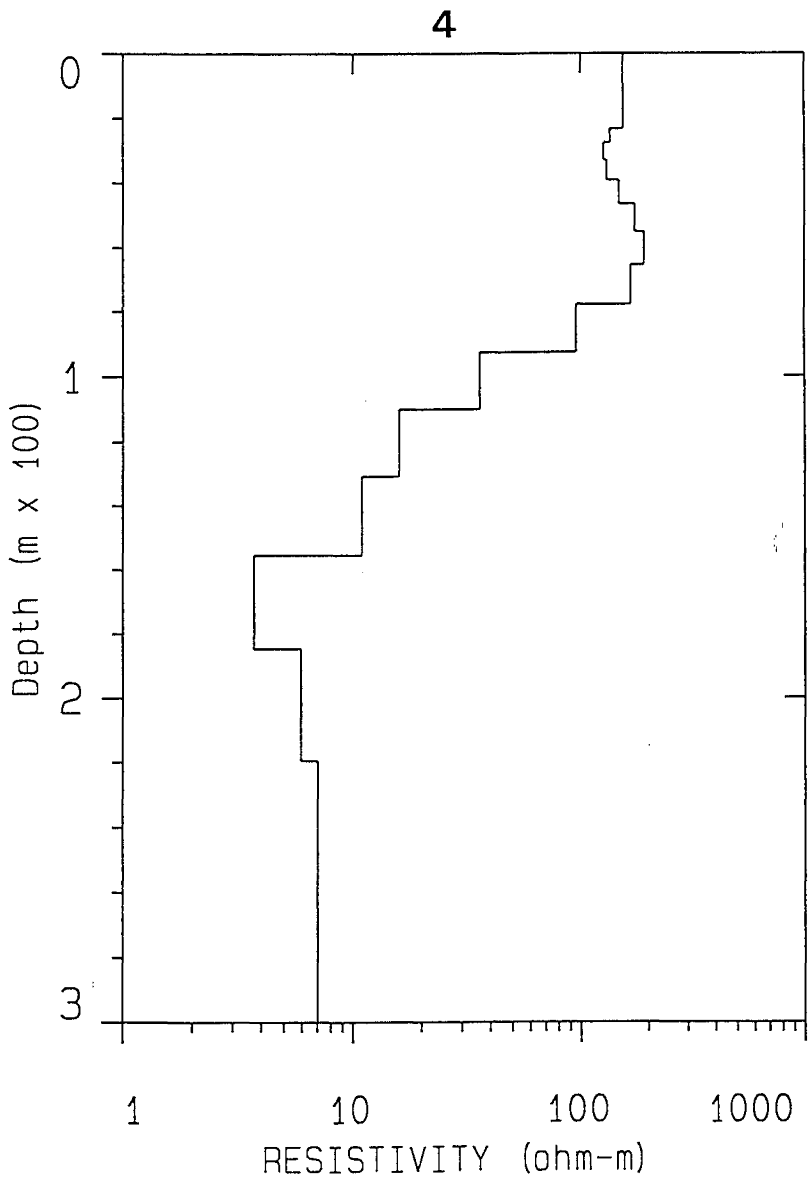

0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

2

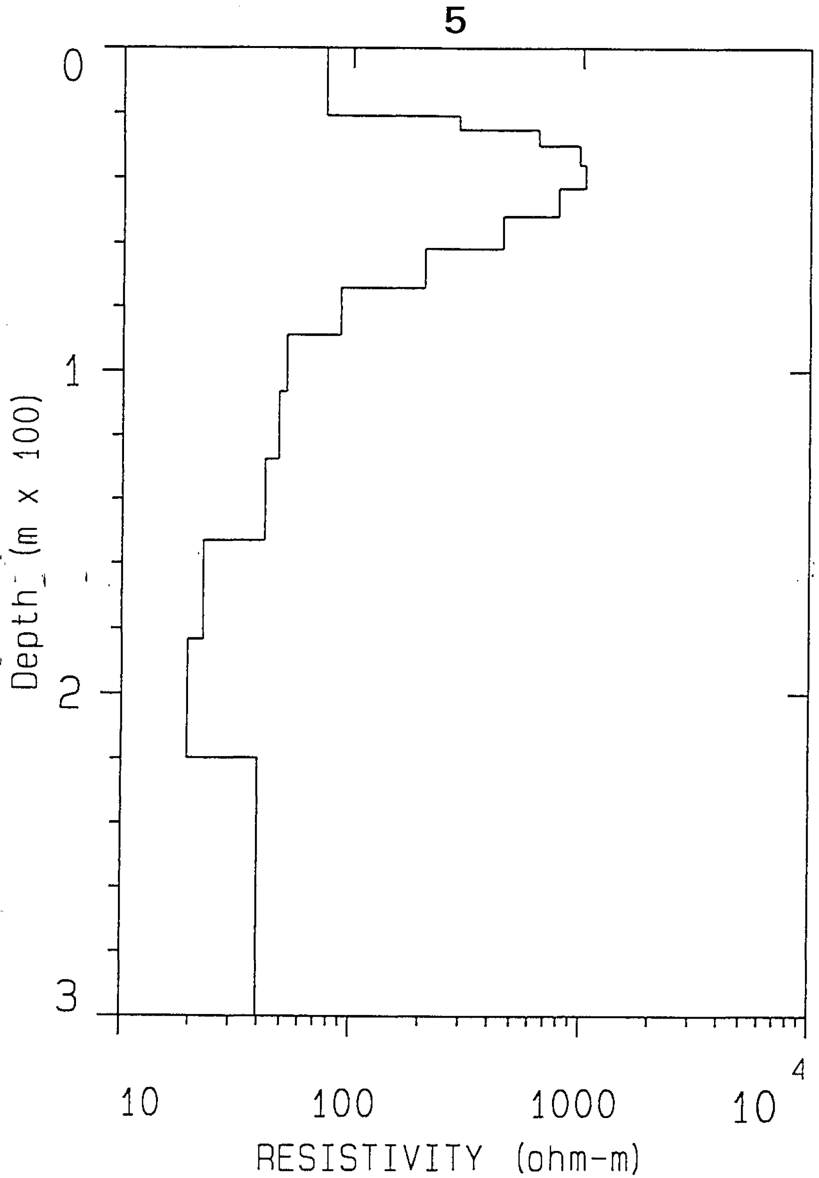

0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

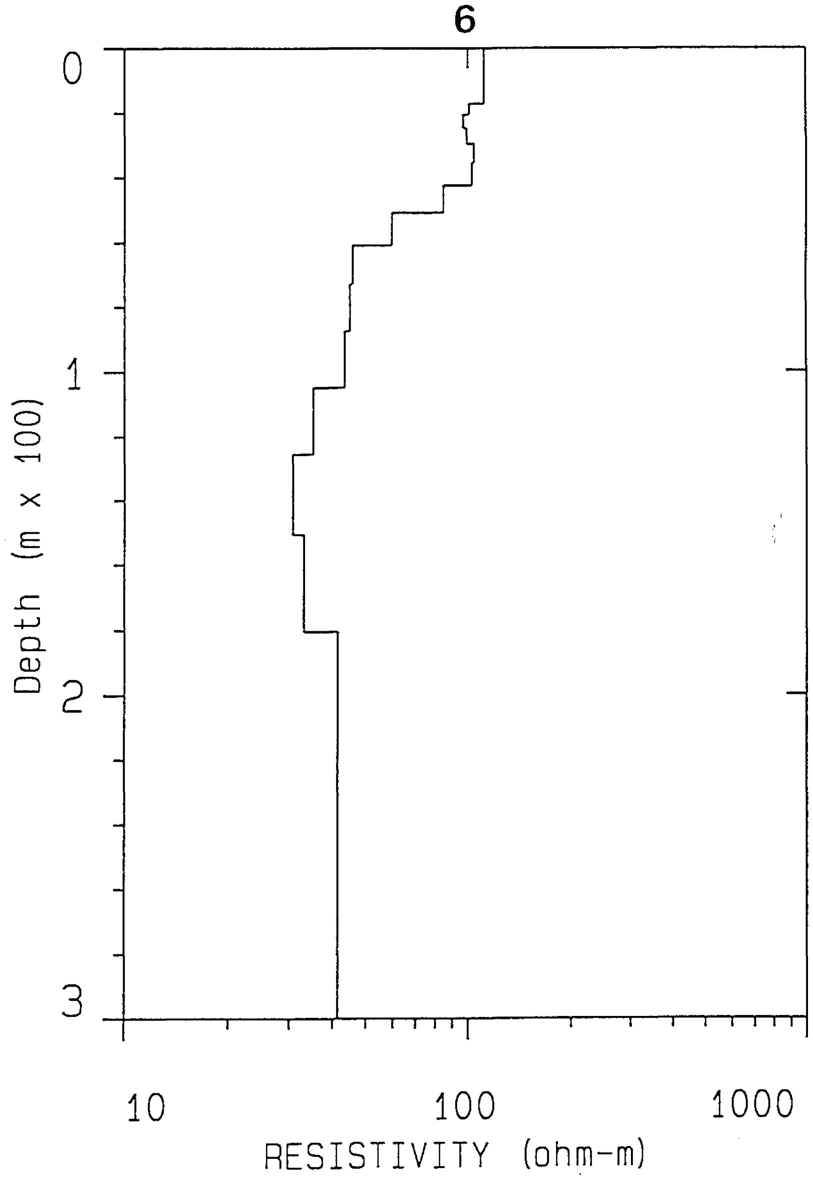


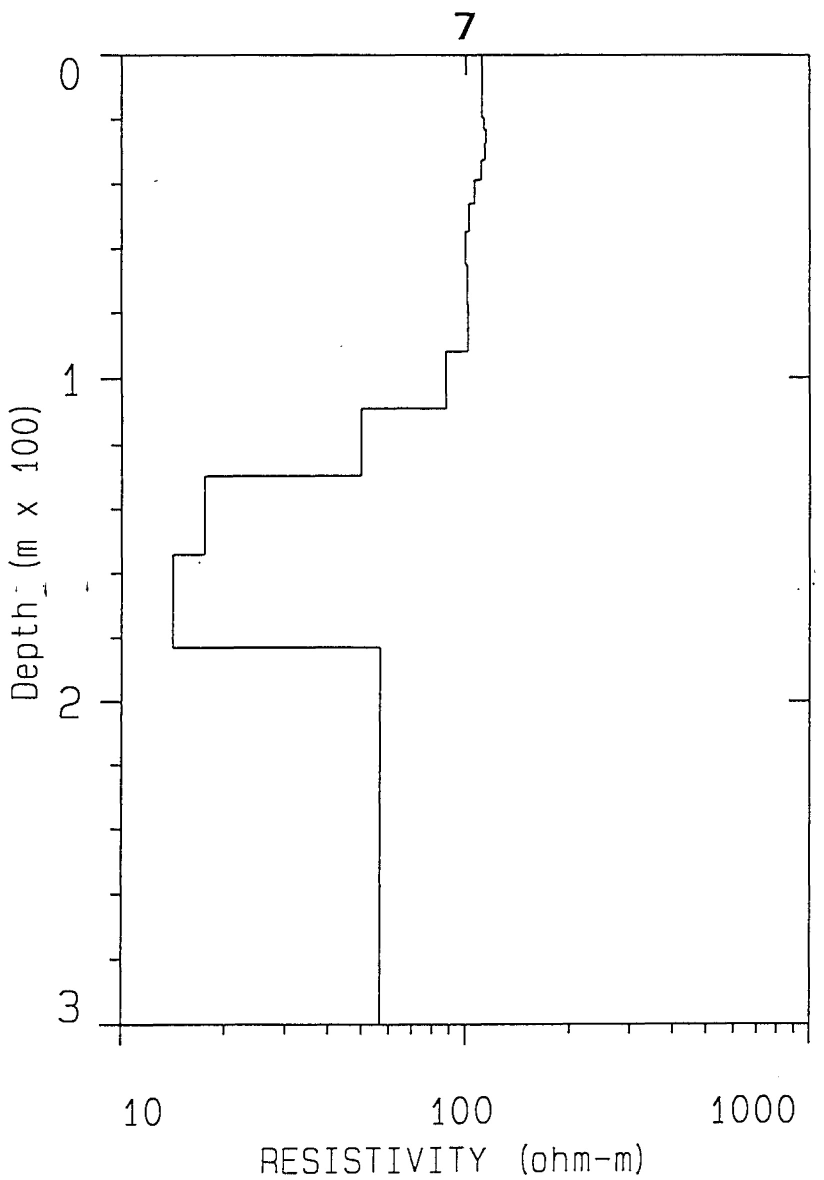
3
0
1
2
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

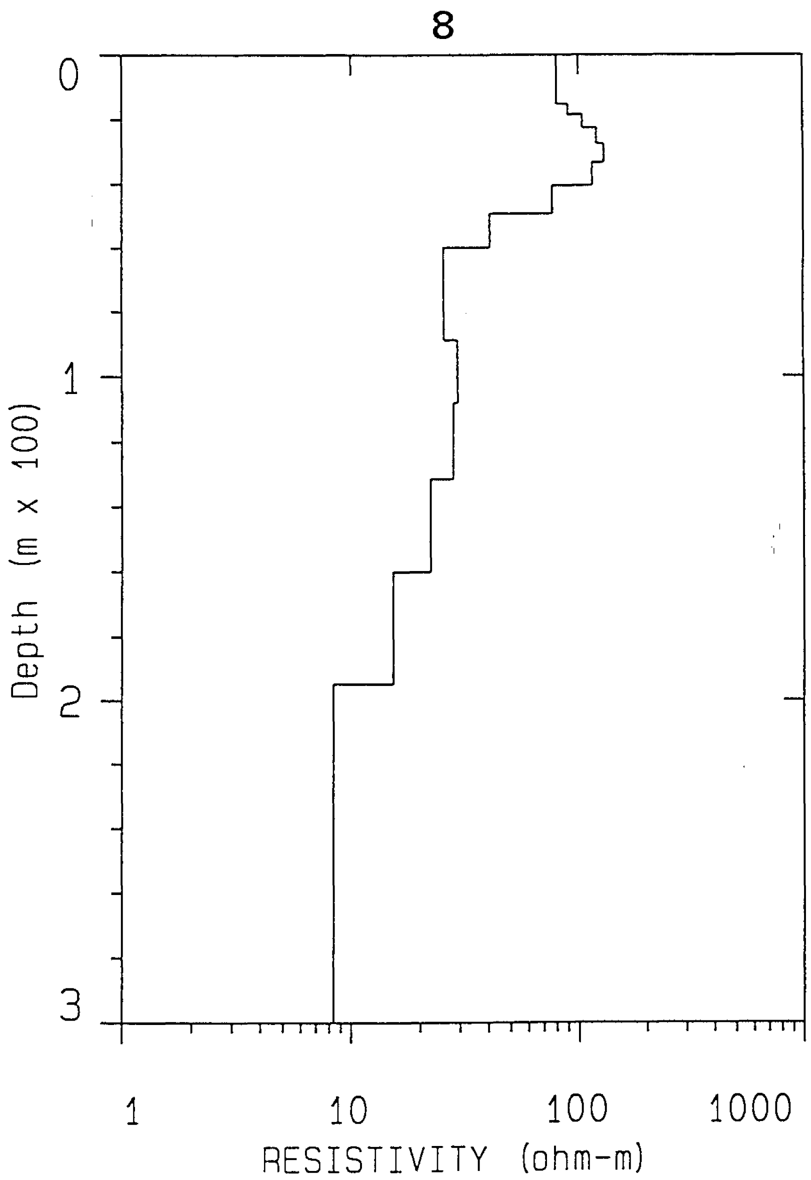


4
0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

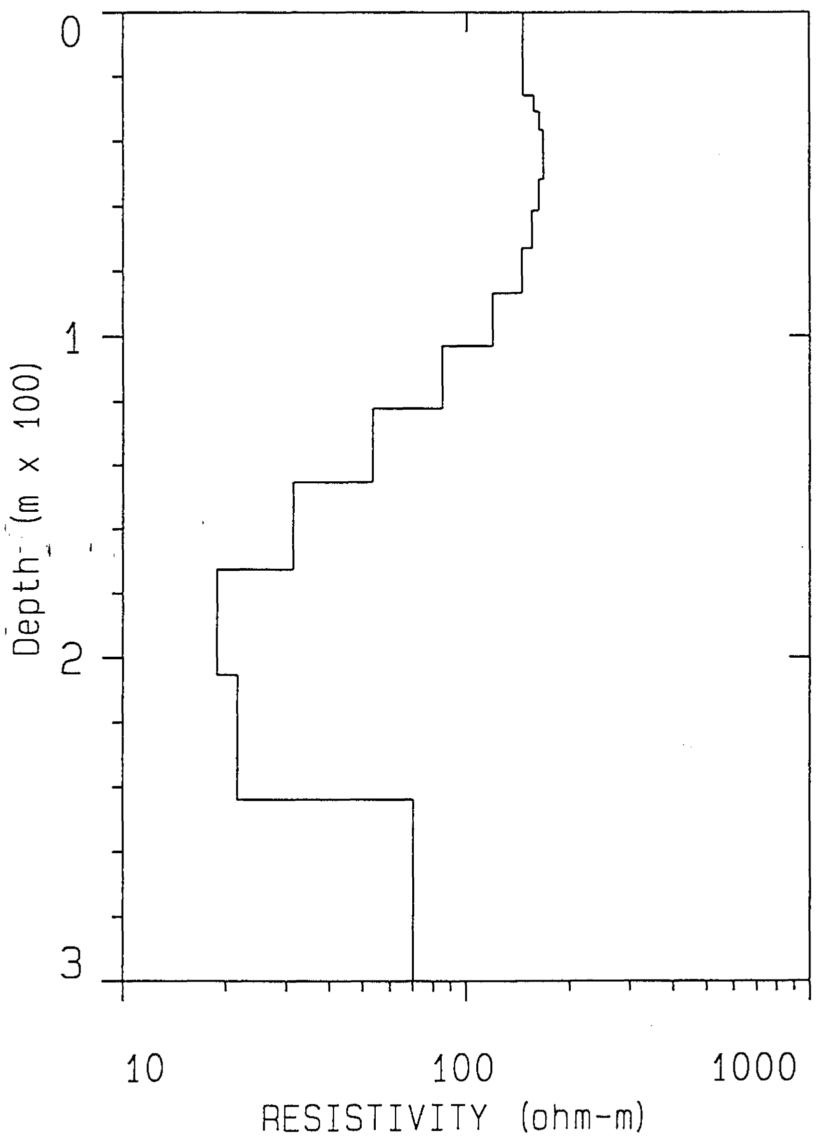

5
0
1
2
3
Depth (m x 100)
10
100
1000
10 4
RESISTIVITY (ohm-m)


6
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

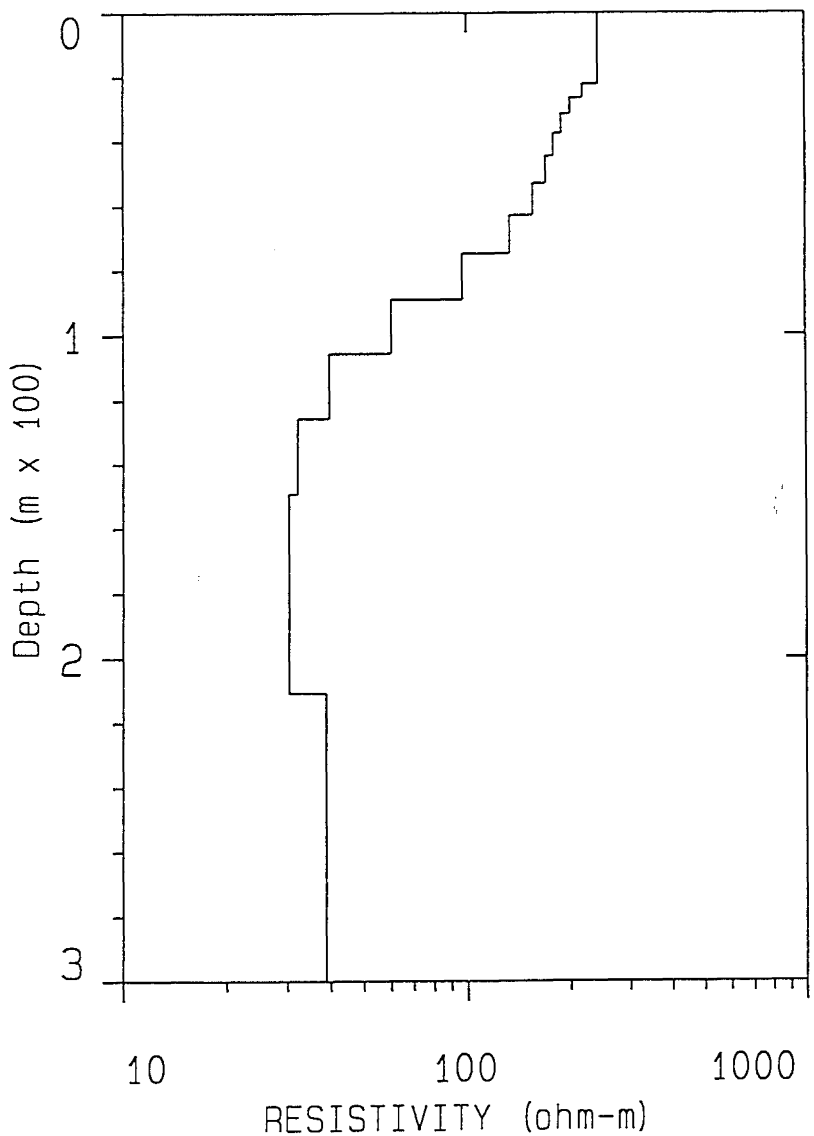

7
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

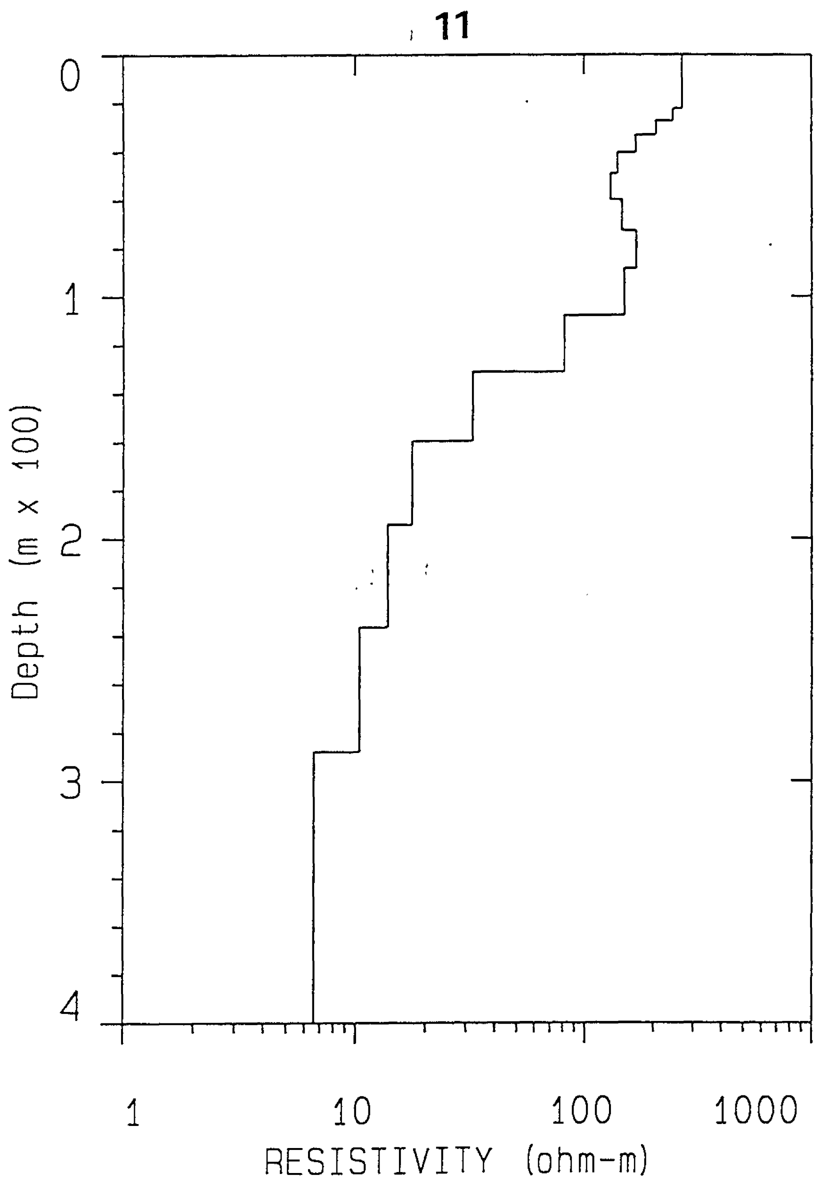

8
0
1
2
3
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

9


0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

10


0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

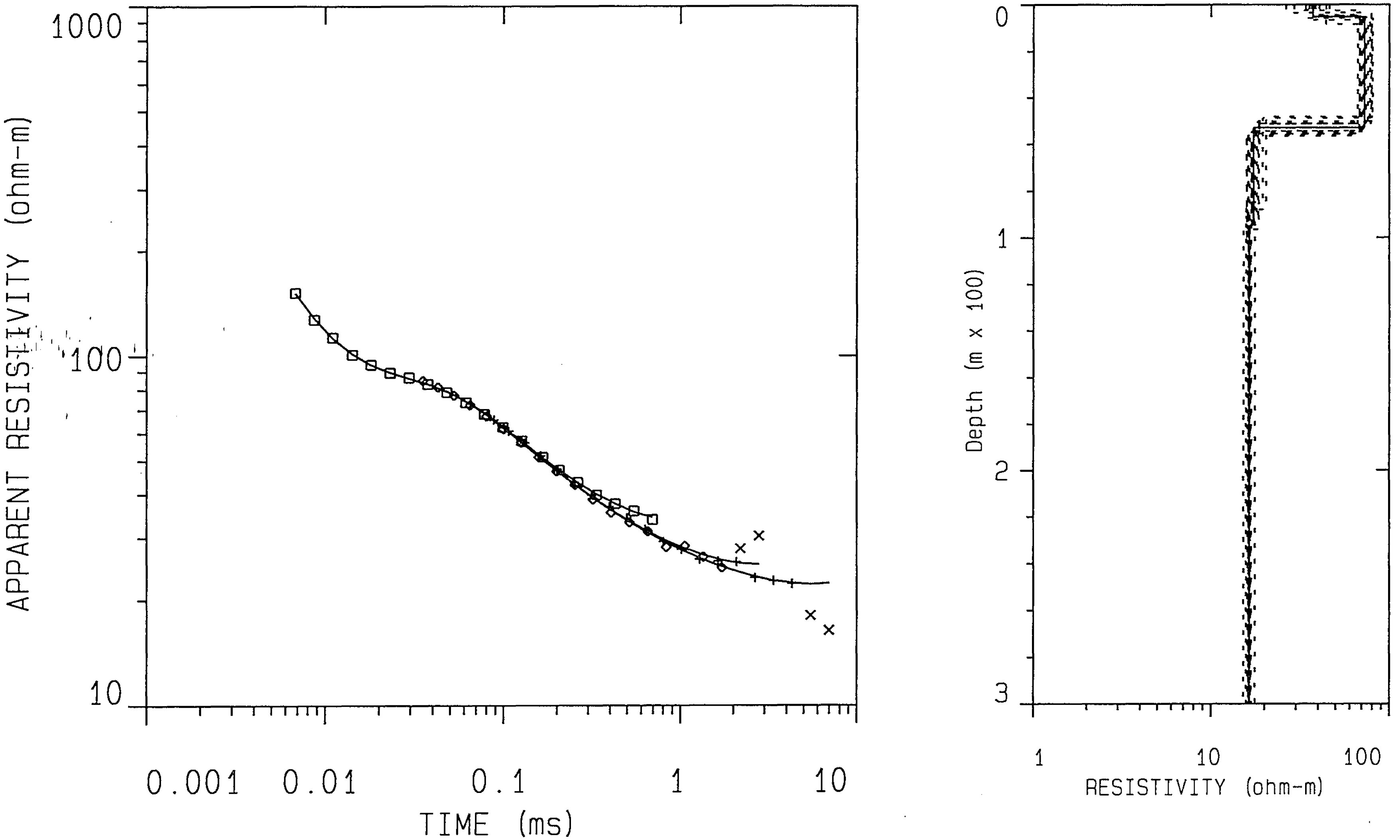

11
0
1
2
3
4
Depth (m x 100)
1
10
100
1000
RESISTIVITY (ohm-m)

IV-II: SURVEY LINE B.

IV-II-I: APPARENT RESISTIVITY CURVES AND EQUIVALENCE MODELS.

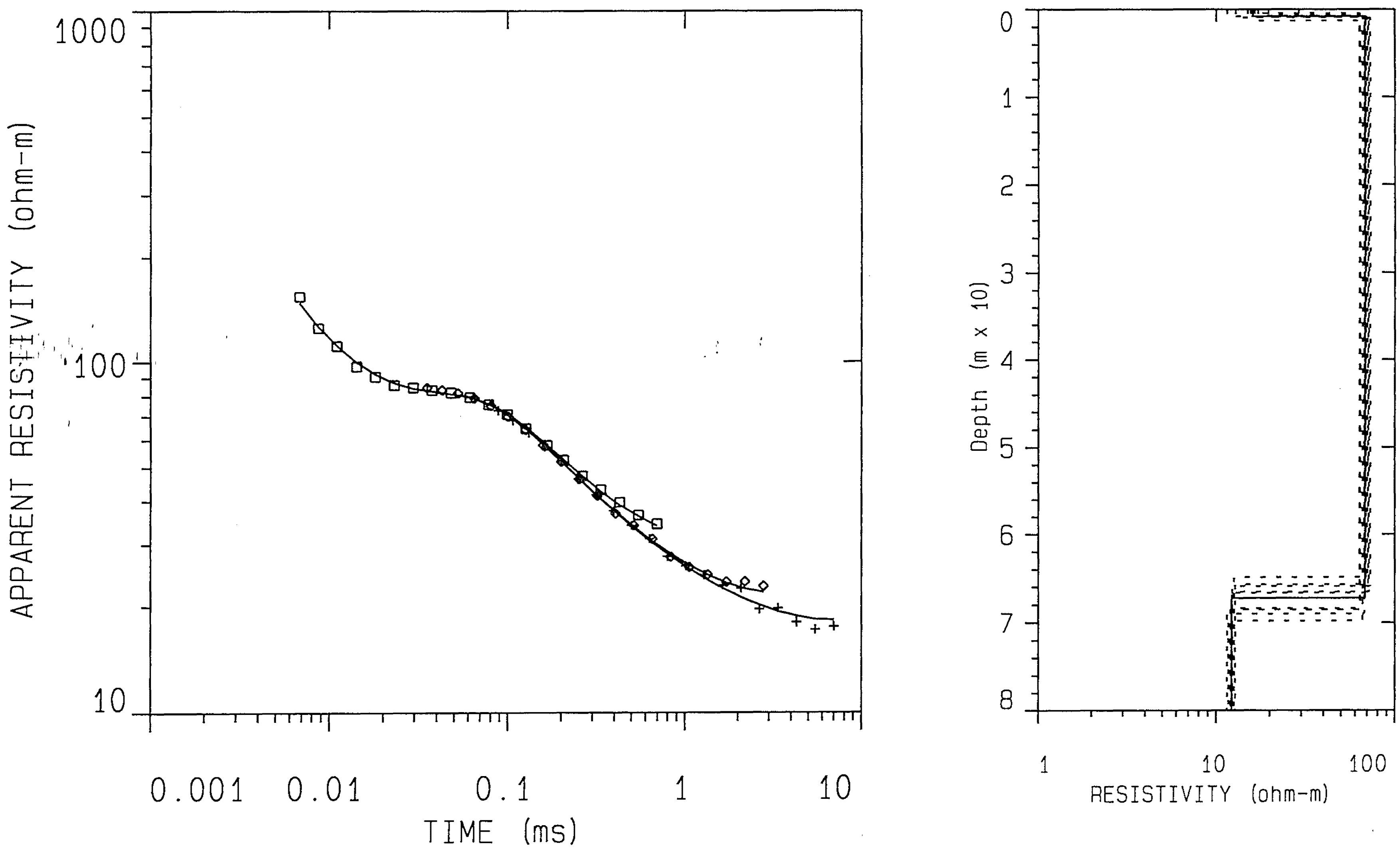
MTFYFFE1	=	SOUNDING 1
MTFYFFE2	=	SOUNDING 2
MTFYFFE3	=	SOUNDING 3
MTFYFFE4	=	SOUNDING 4
MTFYFFE5	=	SOUNDING 5

MTFYFFE1

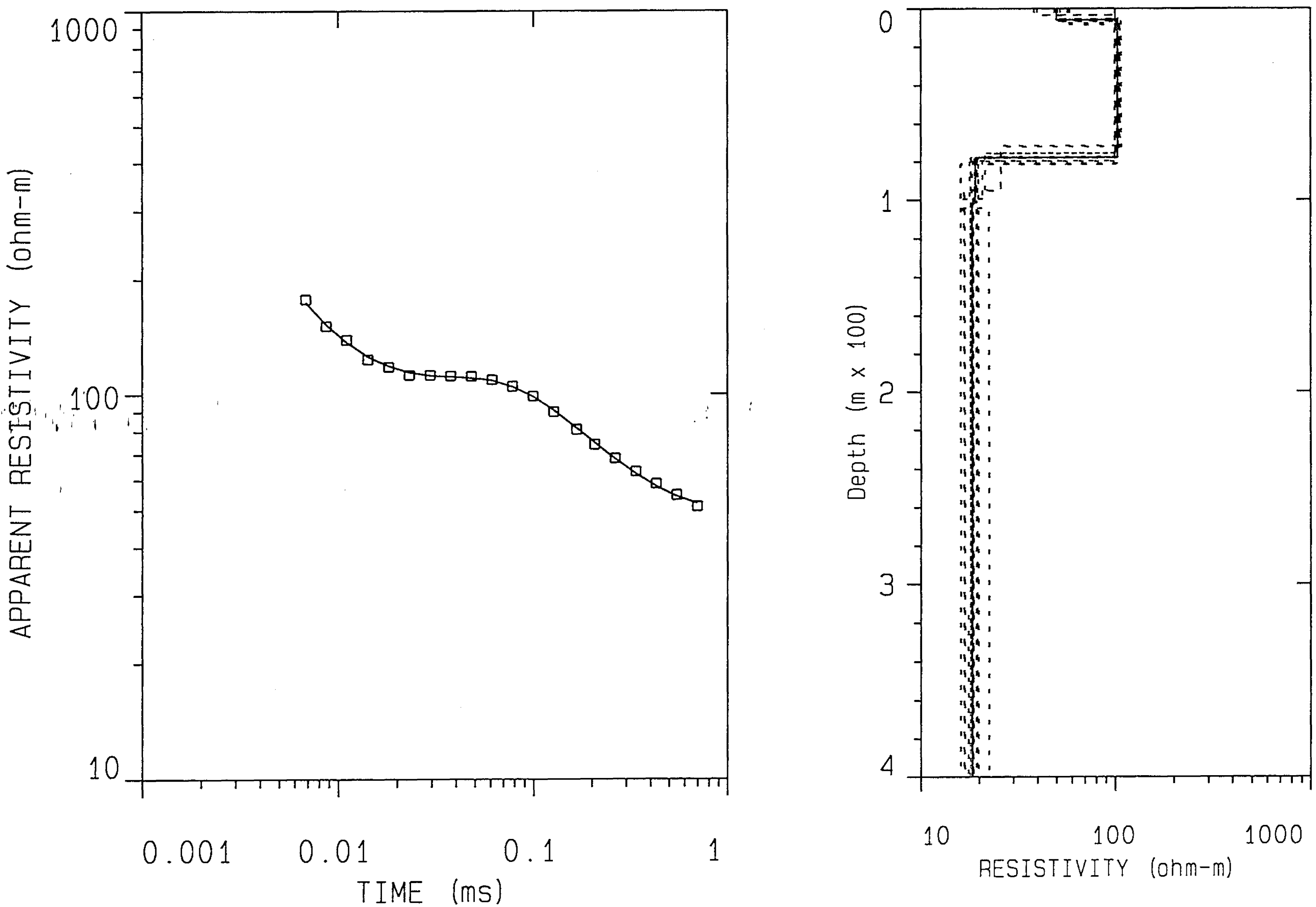


APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.001
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
3
1
10
100
RESISTIVITY (ohm-m)

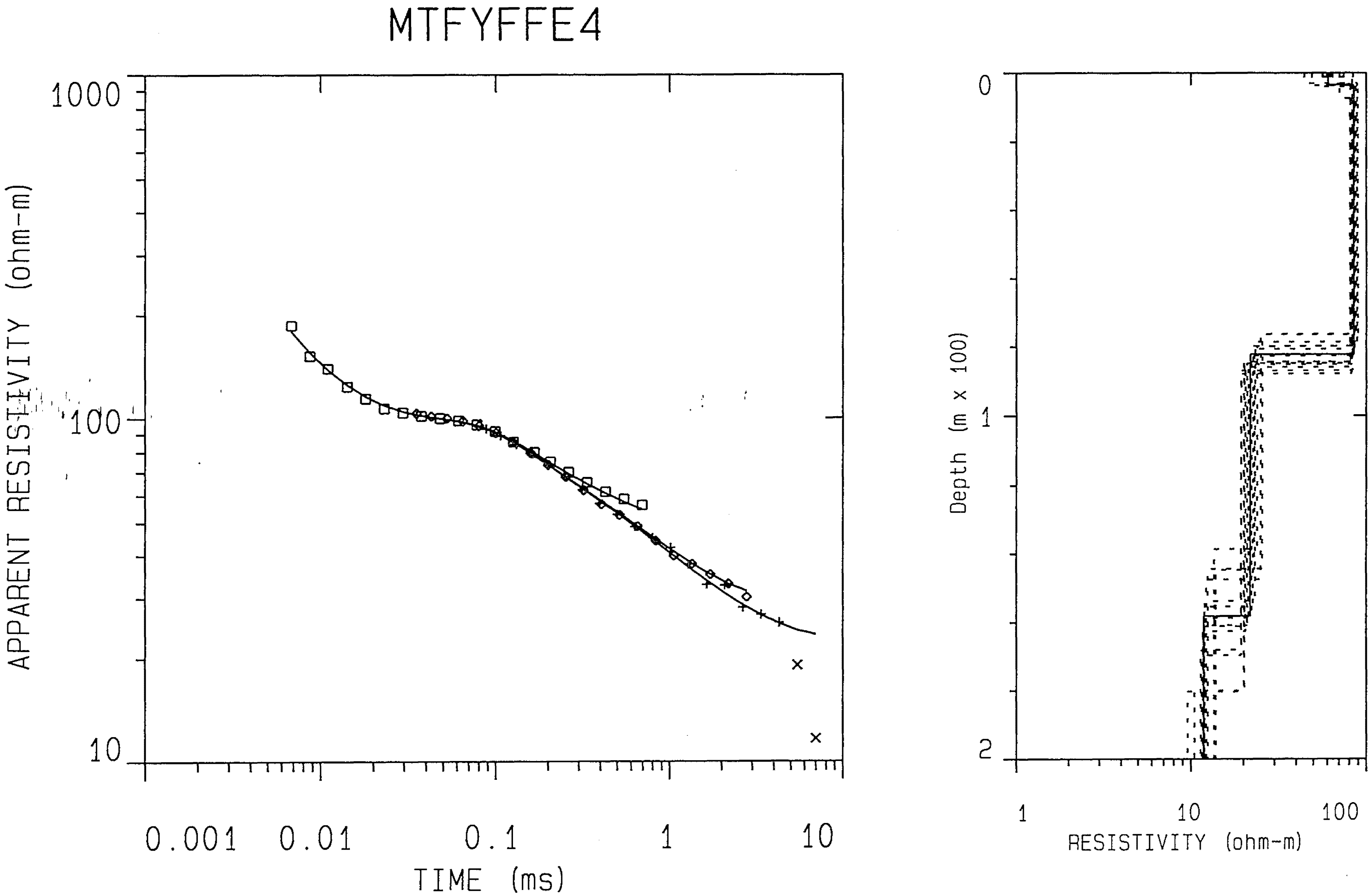
MTFYFFE2


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
8
Depth (m x 10)
1
10
100
RESISTIVITY (ohm-m)

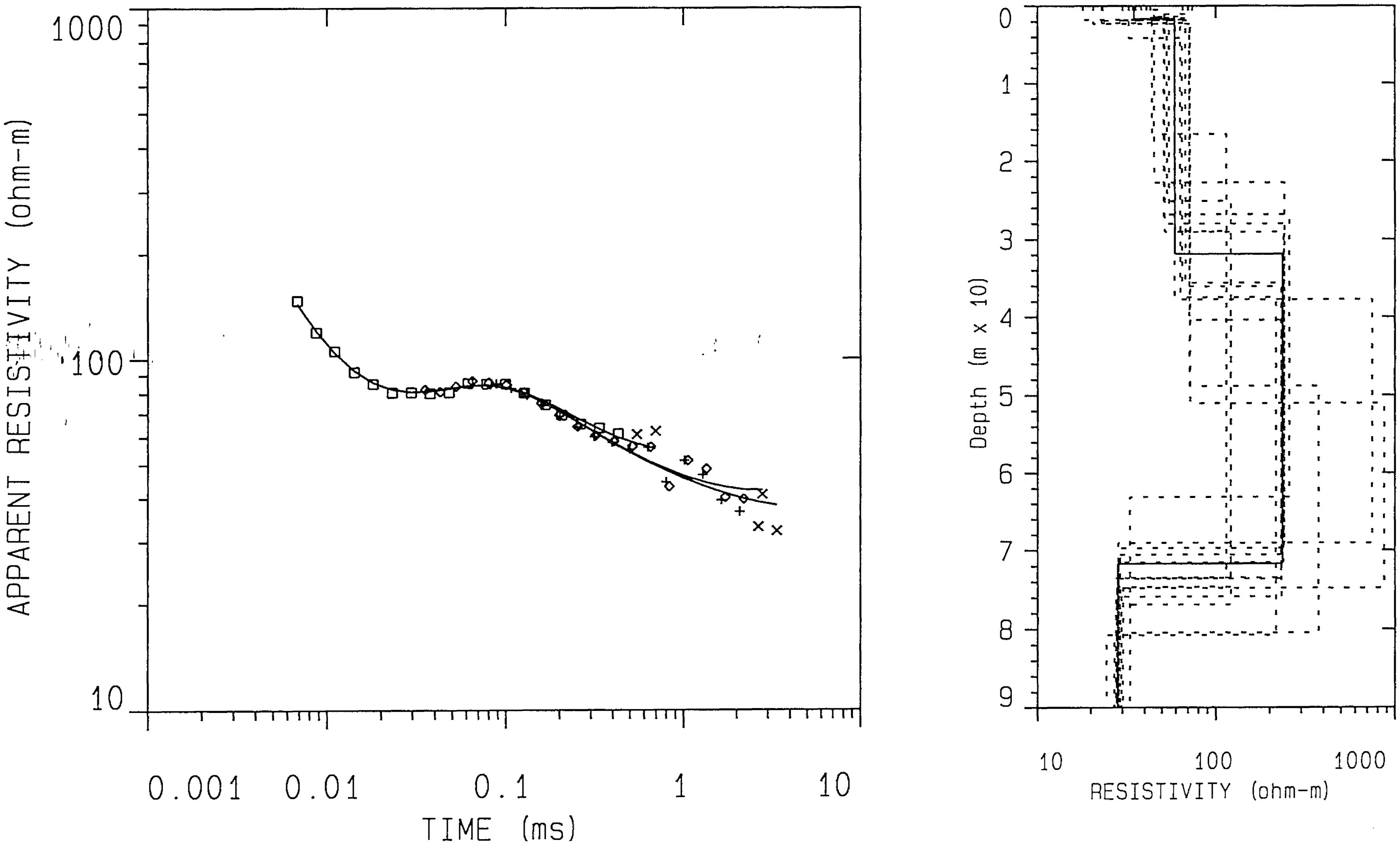
MTFYFFE3



1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
TIME (ms)
0
1
2
3
4
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

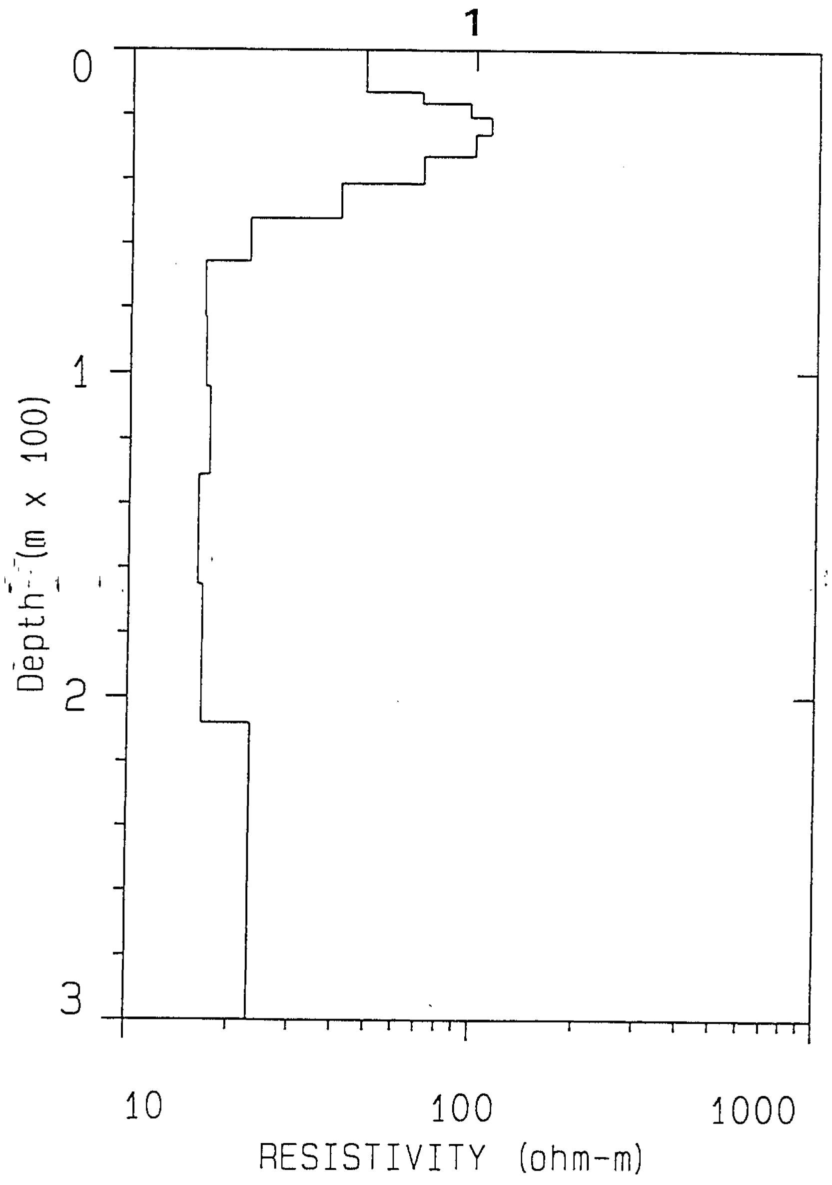

MTFYFFE4
APPARENT RESISTIVITY (ohm-m)
1000
100
10
0.001
0.01
0.1
1
10
TIME (ms)
Depth (m x 100)
0
1
2
1
10
100
RESISTIVITY (ohm-m)

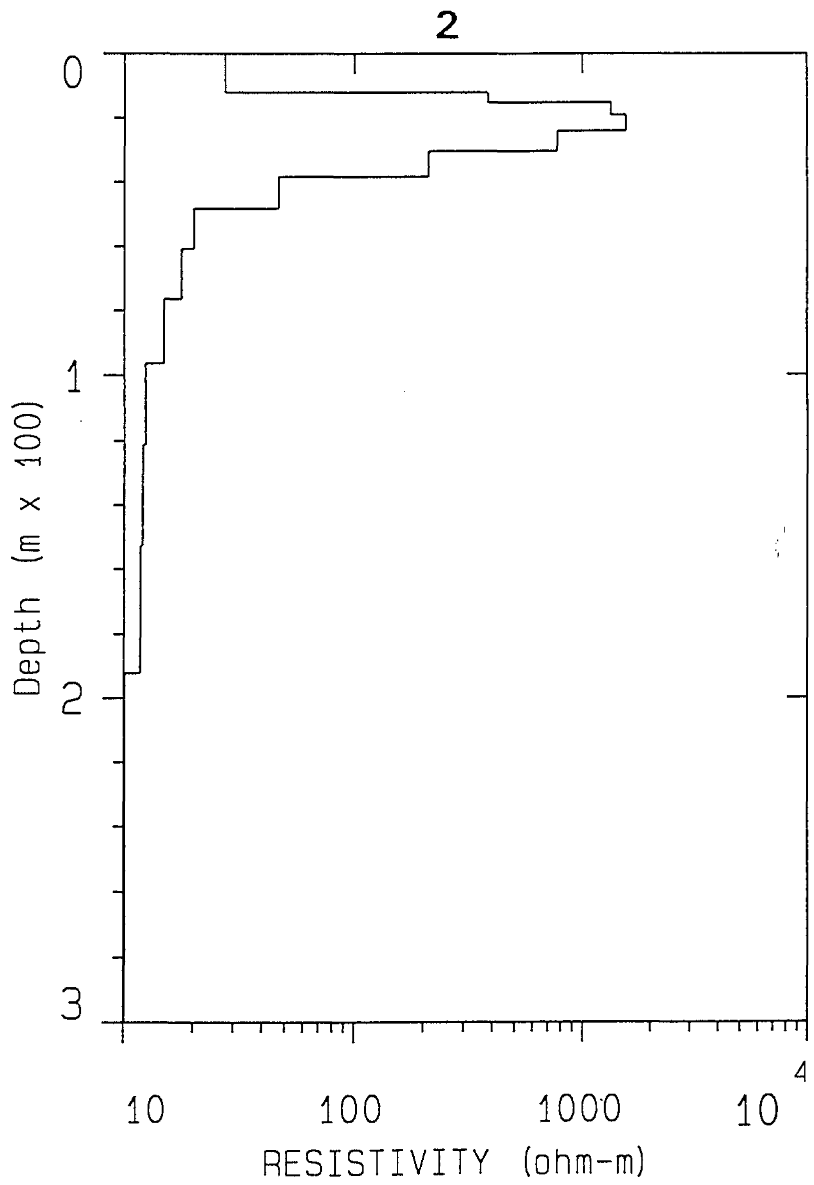
MTFYFFE5



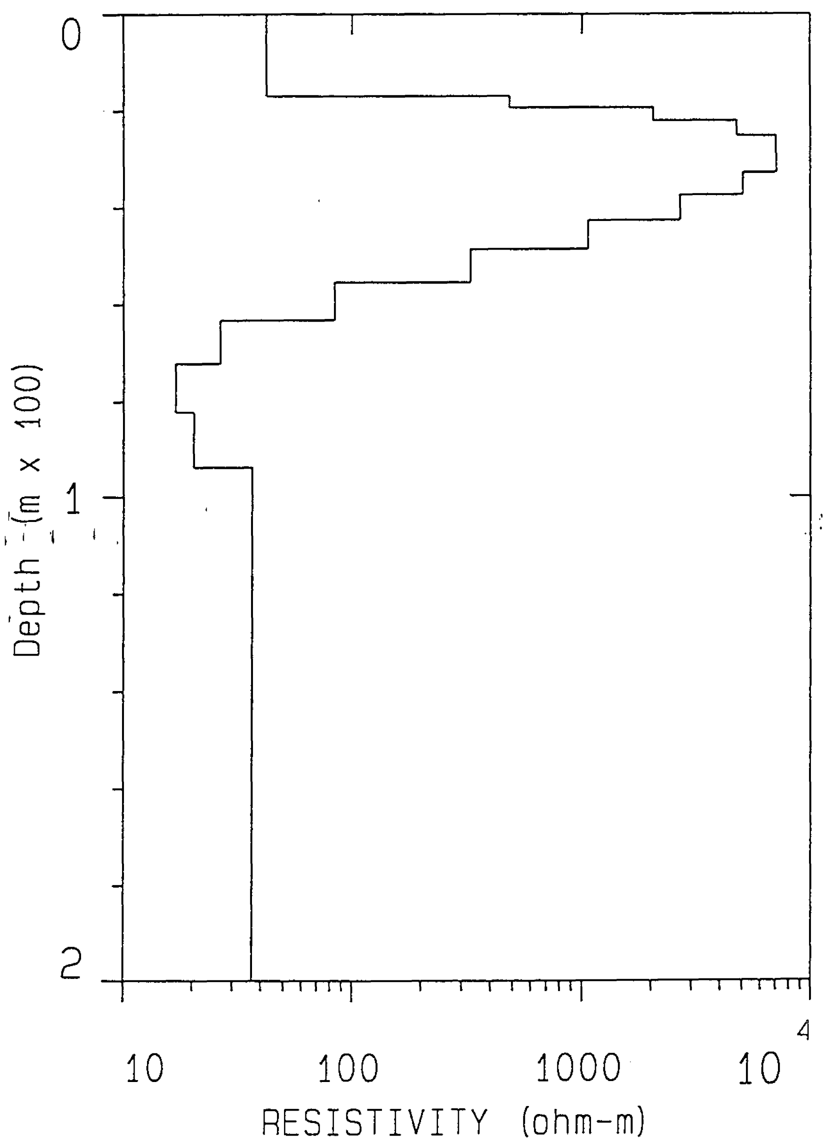
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.001
0.01
0.1
1
10
TIME (ms)
0
1
2
3
4
5
6
7
8
9
Depth (m x 10)
10
100
1000
RESISTIVITY (ohm-m)

IV-II-II: SMOOTH MODELS.


1
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

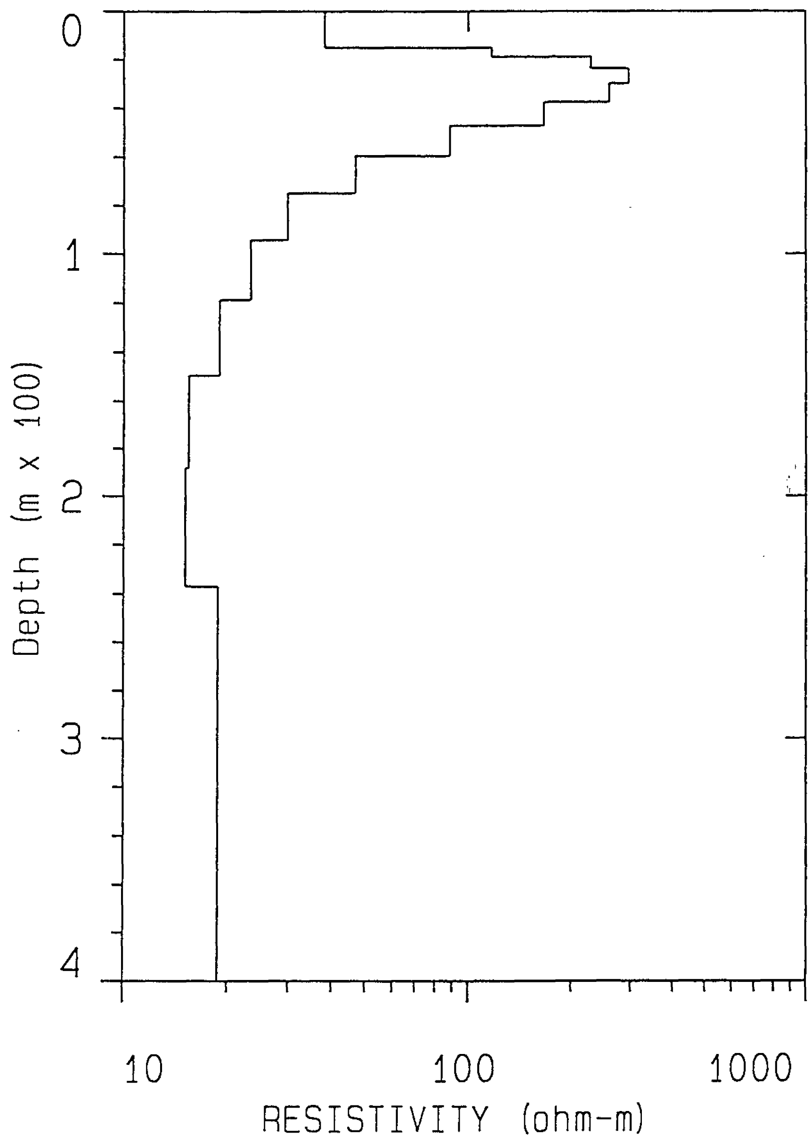

2
0
1
2
3
Depth (m x 100)
10
100
1000
10^4
RESISTIVITY (ohm-m)

3

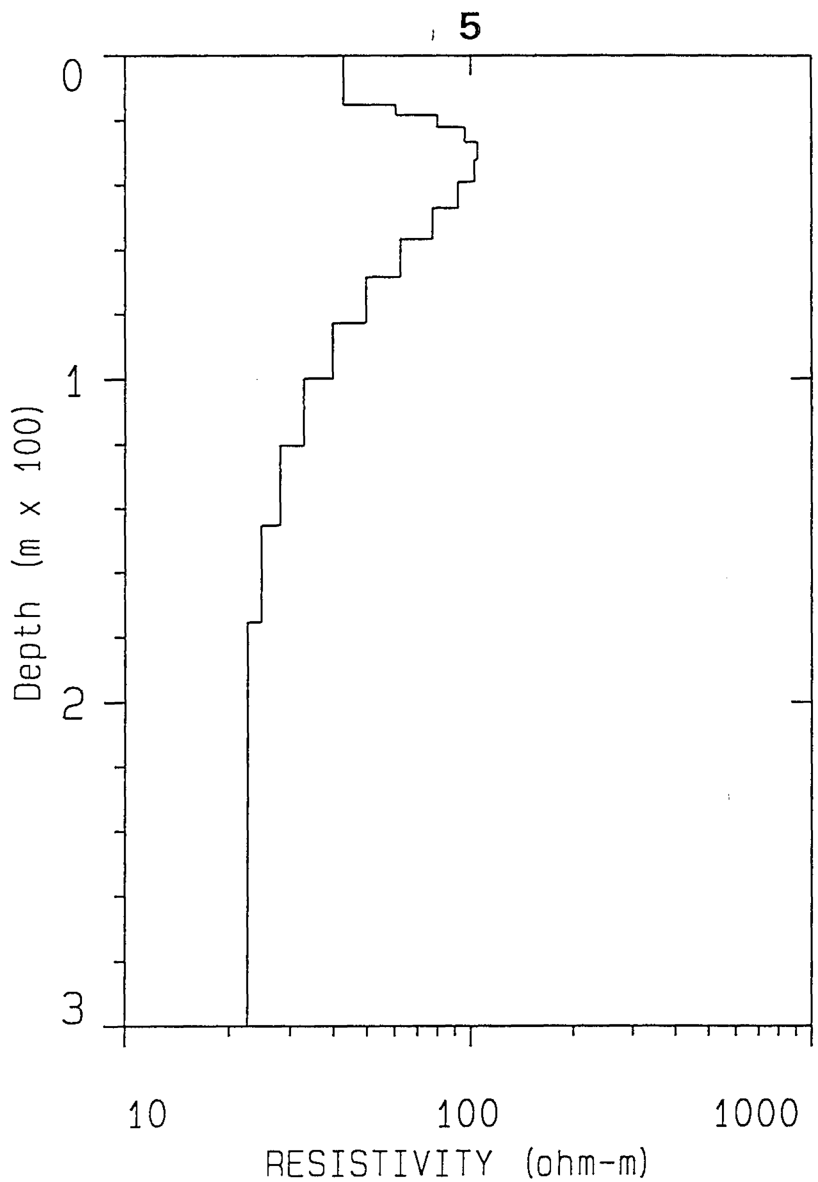


Depth (m x 100)
0
1
2
10
100
1000
10^4
RESISTIVITY (ohm-m)

4



Depth (m x 100)
0
1
2
3
4
10
100
1000
RESISTIVITY (ohm-m)


5
0
1
2
3
Depth (m x 100)
10
100
1000
RESISTIVITY (ohm-m)

APPENDIX V: Pump Testing.

V-I: Introduction.

Before the present study only limited pump testing had been undertaken on the Kaikoura Plains. Those pump tests which had been undertaken were generally only drillers tests giving only the specific yield for that well with no values for either transmisivity or storativity. The location of the pump tests undertaken for this study was wholy influenced by the precence of a suitable well to be pumped and also of a well cose enough in which to monitor the effects of the pumping. Two constant rate discharge tests were performed.

V-II: Specific Capacity Data.

Available specific capacity (SPC) data is presented in Table V.I. The data is limited and shows no obvious areal trend or distinction between aquifers.

Well Number O/31:	Grid Reference	Depth	Yield (m3/day)	Drawdown (m)	SPC (m2/day)
1	660-674		218.3	0.6	4.2
6	614-696		22	0.1	2.5
24	632-678		635	7.2	1
24	632-678		750	5.4	1.6
85	633-692		32.75	7.62	0.05
107	623-702		262	7.62	0.4
107	623-702		982.5	7.62	1.49
108	624-700		524	1.98	3.06
121	659-721		2449	2.665	10.6
128	606-652		668.1	2.97	2.6
146	620-664		259.2	0.75	4
155	616-657		1080	3.7	3.38
156	657-684		587.5	3.76	1.8
157	601-681		118.36	0.76	1.8
158	610-713		129.6	0.17	8.8
164	624-742		25.9	1.2	0.25
175	614-706		916	5.8	1.83
185	617-715		1500	2.1	8.26
186	637-721		752	3.5	2.49
186	637-721		163.75	3.6	0.5
204	637-717		3267	8.6	4.41
206	605-714		1254	14.5	1
210	6082-6518		65	3.6	0.21
212	609-618		458.5	6.2	0.86
213	6435-6965		1140.48	10.2	1.29
215	6040-7165		1310	12	1.26

Table V-I. Kaikoura Plains Specific Capacity Data.

V-III: Beach Road Pump Test.

INTRODUCTION

A constant discharge pump test was carried out on the Kaikoura District Councils bore at the corner of Mill and Beach Roads (Figure V.I). The pumped well (O31/115) penetrates the confined region of Aquifer 1 and has a slotted casing screen from 20.7m to 23.7m within this aquifer. The well was pumped at a constant rate of 0.768m^3/min from 09:20 on the 8/6/95 untill 20:30 on the 8/6/95. Only one observation well was available (O31/3), also pentrating the confined region of Aquifer 1 at a distance of 410m from the pumped well. This well has a permanently positive artesian head. To record the change in artesian pressure at the observation well a pressure transducer and Kianga Data Logger were installed. A 20mm tidal fluctuation was also picked up by the pressure transducer for which the draw down data was corrected. Water levels changes for both the pumped well and the observation well were recorded manually during both drawdown and recovery while the pressure transducer recorded drawdown and recovery at the observation well. The transducer was left on the observation well for several days after the pump testing had stopped to continue to monitor recovery and also to record background water levels and tidal fluctuations.

DATA ANALYSIS

Aquifer transmissivity was determined using data from both the pumped well and the observation well and the storage coefficient was determined using the observation well data.

The drawdown curve for the pumped well has the appearance of two combined drawdown curves suggesting some sort of boundary effect caused by a decrease in permeability. The first, relativly shallow drawdown curve suggests higher transmissivity of aquifer materials in close vicinity to the pumped well, but, as the cone of depression expands it becomes influenced by less permeable aquifer materials and so the drawdown starts to increase again, and will likely continue to increase, possibly draining the aquifer. This being the case, the second drawdown curve was used to determine a value for transmissivity as it represents the long term transmissivity of the aquifer.

The drawdown in the observation well was delayed by about 70 minutes which suggests a very low transmissivity. Recovery in the observation well was also anomalously slow as it continued to draw down for almost 10 hours after pumping

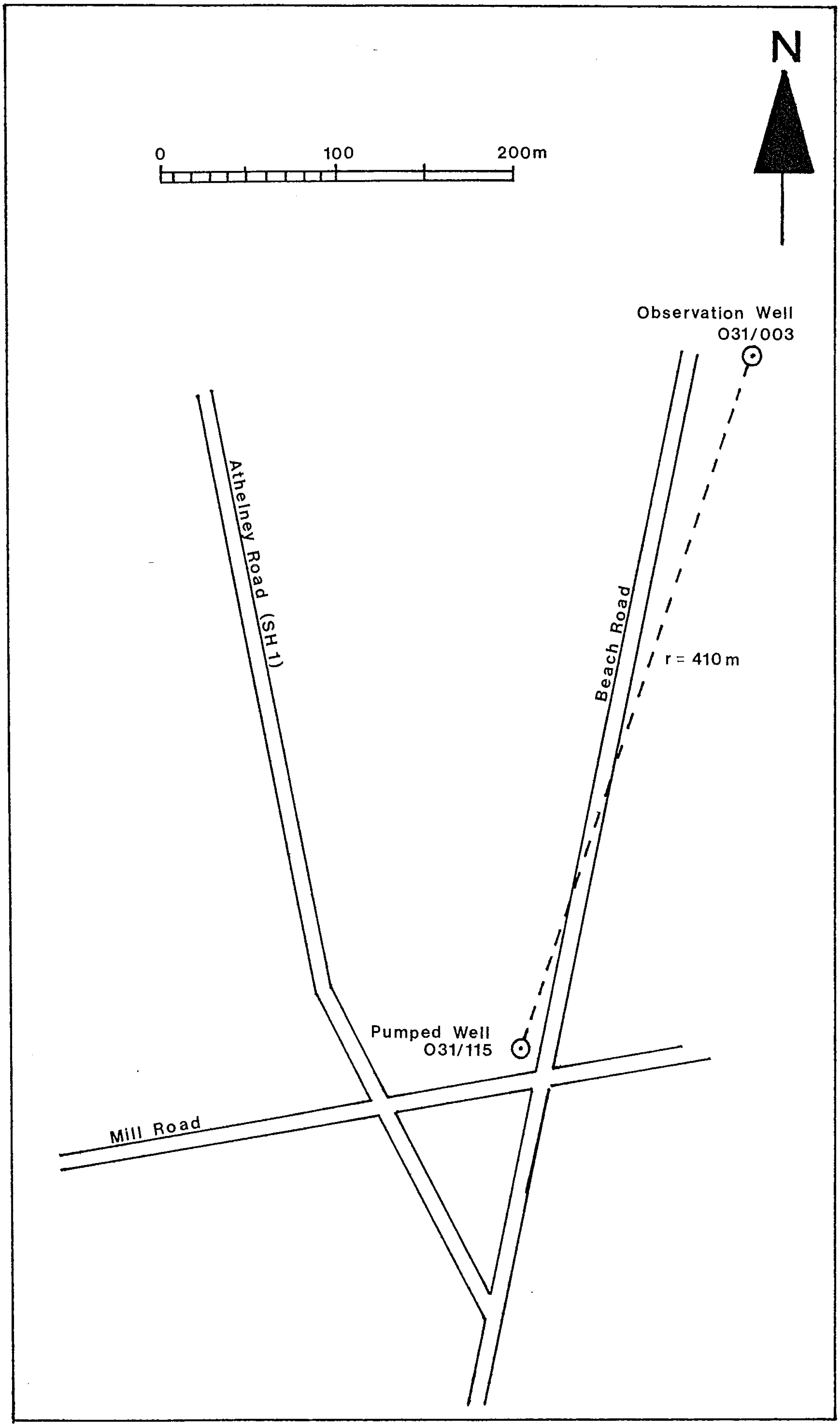


FIGURE V-I. Pump Test Location.

had ceased. Because of this delayed response to the turning off of the pump, the observation well recovery data was not used for analysis.

AQUIFER CHARACTERISTICS

Pump testing of well O31/0115 has allowed the determination of the following aquifer characteristics using the Jacob unsteady-state confined method:

Method of Analysis	**Transmissivity (m^3/min/m)**	**Storativity**
Pumped well drawdown	0.041	
Pumped well recovery	0.045	
Observation well Drawdown	0.21	7.4×10^{-4}

These characteristics are consistent with a low yielding aquifer, the value obtained for the storage coefficient of the aquifer is consistent with that of a confined aquifer.

V-III-I: Pump Test Data.

BEACH ROAD PUMPING TEST

PUMPED WELL - O31/115

Pumping started at 09:20 on 8/6/95
Initial depth to water = 4.075m

Time since pumping started (min)	Depth to water (m)	Draw-down (m)	Time since pumping started (min)	Depth to water (m)	Draw-down (m)
0	4.075	0.000	85	7.457	3.382
2.5	6.338	2.263	90	7.493	3.418
3	6.383	2.308	95	7.528	3.453
4	6.442	2.367	100	7.565	3.490
5	6.490	2.415	110	7.650	3.575
6	6.541	2.466	125	7.725	3.650
7	6.575	2.500	141	7.818	3.743
8	6.609	2.534	160	7.938	3.863
9	6.639	2.564	180	8.110	4.035
12	6.665	2.590	200	8.161	4.086
13	6.686	2.611	220	8.268	4.193
14	6.709	2.634	245	8.382	4.307
15	6.730	2.655	260	8.450	4.375
16	6.748	2.673	280	8.544	4.469
17	6.762	2.687	305	8.646	4.571
18	6.780	2.705	320	8.711	4.636
19	6.801	2.726	360	8.869	4.794
20	6.824	2.749	380	8.942	4.867
21	6.843	2.768	400	9.013	4.938
22	6.866	2.791	420	9.084	5.009
24	6.888	2.813	440	9.151	5.076
26	6.917	2.842	460	9.228	5.153
28	6.942	2.867	480	9.287	5.212
30	6.972	2.897	500	9.350	5.275
32	7.002	2.927	522	9.421	5.346
34	7.038	2.963	550	9.502	5.427
39	7.070	2.995	580	9.580	5.505
45	7.122	3.047	610	9.658	5.583
50	7.171	3.096	640	9.727	5.652
55	7.208	3.133	670	9.790	5.715
60	7.257	3.182	Pumping stopped at 20		-4.075
65	7.300	3.225	on 8/6/95		-4.075
70	7.339	3.264	671	7.745	3.670
75	7.376	3.301	672	7.620	3.545
80	7.420	3.345	673	7.544	3.469

674	7.439	3.364	970	6.165	2.090
675	7.452	3.377	1000	6.092	2.017
676	7.419	3.344	1030	6.025	1.950
677	7.394	3.319	1060	5.965	1.890
678	7.372	3.297	1090	5.901	1.826
679	7.351	3.276	1120	5.843	1.768
680	7.334	3.259	1150	5.788	1.713
681	7.316	3.241	1180	5.738	1.663
682	7.305	3.230	1210	5.686	1.611
683	7.289	3.214	1240	5.641	1.566
684	7.277	3.202	1270	5.598	1.523
685	7.265	3.190	1410	5.416	1.341
686	7.253	3.178	1454	5.360	1.285
687	7.246	3.171	1515	5.283	1.208
688	7.237	3.162	1570	5.220	1.145
689	7.225	3.150	1595	5.190	1.115
690	7.217	3.142	1655	5.127	1.052
695	7.175	3.100	1735	5.054	0.979
700	7.141	3.066			
705	7.105	3.030			
710	7.073	2.998			
715	7.048	2.973			
720	7.022	2.947			
725	6.996	2.921			
730	6.975	2.900			
740	6.923	2.848			
750	6.875	2.800			
760	6.830	2.755			
770	6.788	2.713			
790	6.710	2.635			
820	6.600	2.525			
840	6.534	2.459			
860	6.481	2.406			
880	6.409	2.334			
910	6.320	2.245			
940	6.242	2.167			

OBSERVATION WELL - O31/003

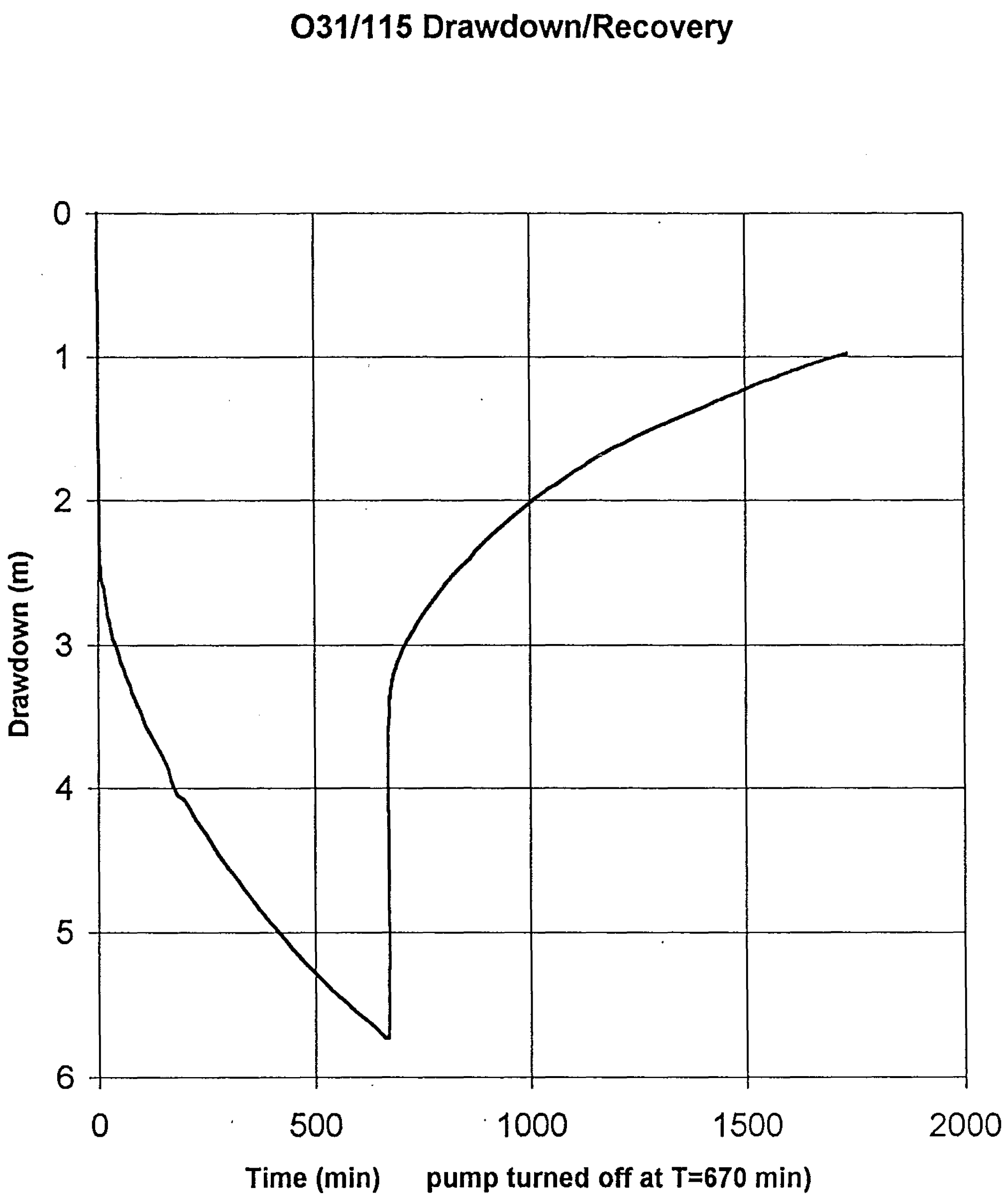
Pumping started at 09:20 on 8/6/95
Initial water level = +0.649m
r = 410m

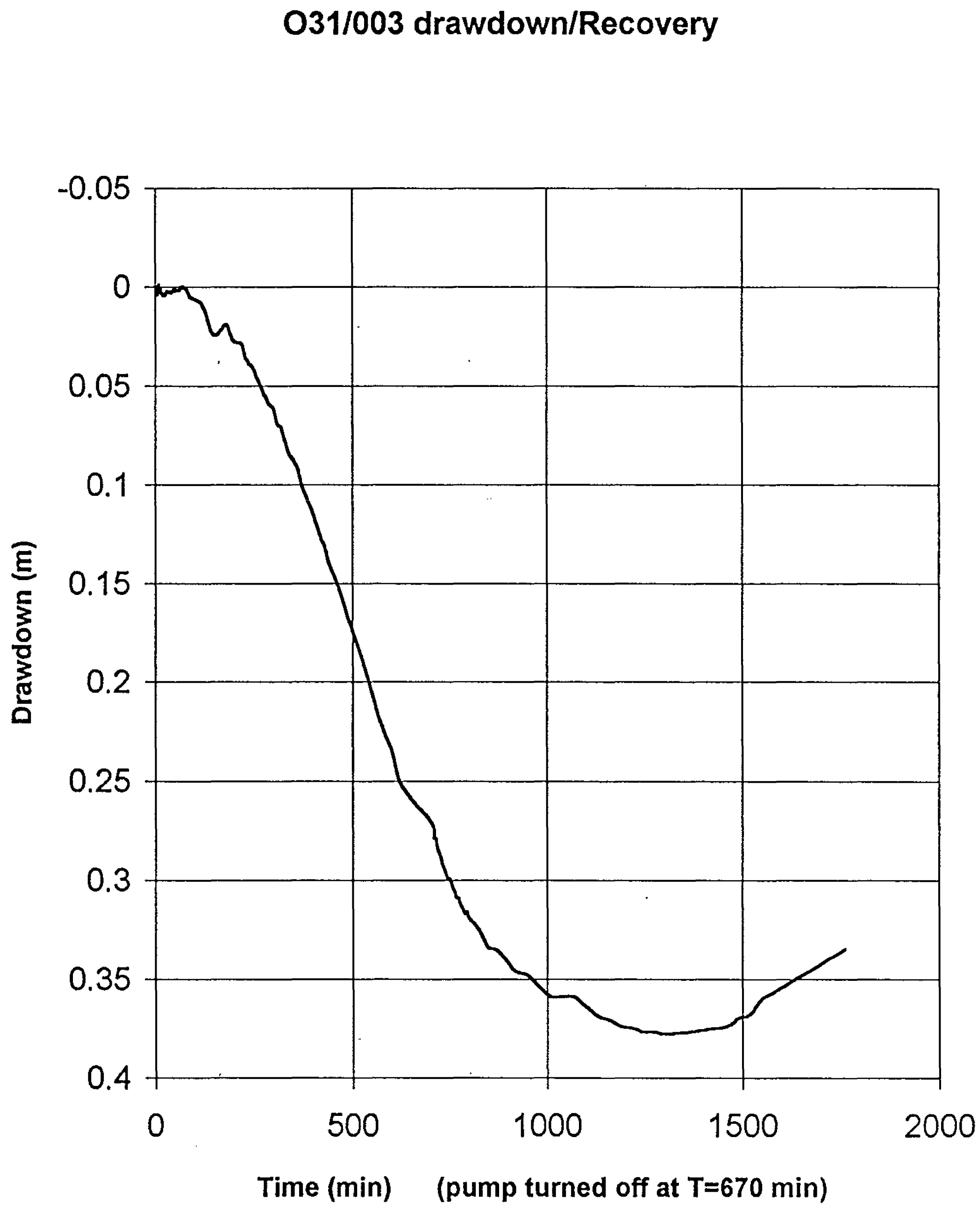
Time since pumping started (min)	Depth to water (m)	Draw-down (m)
0	0.649	0
1	0.648	0.001
2	0.645	0.004
3	0.648	0.001
4	0.647	0.002
5	0.647	0.002
6	0.646	0.003
7	0.645	0.004
8	0.649	0
9	0.65	-0.001
10	0.647	0.002
15	0.648	0.001
20	0.645	0.004
25	0.645	0.004
30	0.647	0.002
40	0.646	0.003
50	0.648	0.001
60	0.647	0.002
70	0.649	0
80	0.648	0.001
90	0.644	0.005
120	0.64	0.009
150	0.625	0.024
180	0.63	0.019
190	0.626	0.023
200	0.622	0.027
210	0.621	0.028
220	0.62	0.029
230	0.613	0.036
235	0.612	0.037
240	0.61	0.039
250	0.608	0.041
260	0.603	0.046
270	0.598	0.051
275	0.595	0.054
280	0.594	0.055

Time since pumping started (min)	Depth to water (m)	Draw-down (m)
290	0.59	0.059
300	0.588	0.061
305	0.585	0.064
310	0.58	0.069
320	0.578	0.071
330	0.571	0.078
340	0.565	0.084
350	0.562	0.087
360	0.558	0.091
370	0.55	0.099
380	0.545	0.104
390	0.54	0.109
400	0.535	0.114
410	0.528	0.121
420	0.522	0.127
430	0.518	0.131
440	0.51	0.139
460	0.5	0.149
480	0.488	0.161
500	0.475	0.174
520	0.464	0.185
545	0.448	0.201
570	0.43	0.219
600	0.415	0.234
630	0.396	0.253
705	0.378	0.271
710	0.37	0.279
Pumping stopped at 20:30 on 8/6/95		
711	0.374	0.275
712	0.372	0.277
713	0.37	0.279
714	0.37	0.279
715	0.37	0.279
716	0.369	0.28
717	0.368	0.281

718	0.366	0.283
719	0.367	0.282
720	0.365	0.284
725	0.363	0.286
730	0.36	0.289
735	0.356	0.293
740	0.353	0.296
745	0.35	0.299
750	0.35	0.299
755	0.348	0.301
760	0.345	0.304
765	0.343	0.306
770	0.34	0.309
775	0.34	0.309
780	0.337	0.312
785	0.335	0.314
790	0.332	0.317
795	0.333	0.316
800	0.33	0.319
815	0.327	0.322
830	0.323	0.326
850	0.315	0.334
870	0.314	0.335
890	0.31	0.339
920	0.303	0.346
950	0.301	0.348
980	0.295	0.354
1010	0.29	0.359
1040	0.29	0.359
1070	0.29	0.359
1100	0.285	0.364
1130	0.28	0.369
1160	0.278	0.371
1190	0.275	0.374
1220	0.274	0.375
1250	0.272	0.377
1280	0.272	0.377
1310	0.271	0.378
1460	0.275	0.374
1490	0.279	0.37
1520	0.281	0.368
1550	0.289	0.36
1595	0.294	0.355
1760	0.314	0.335

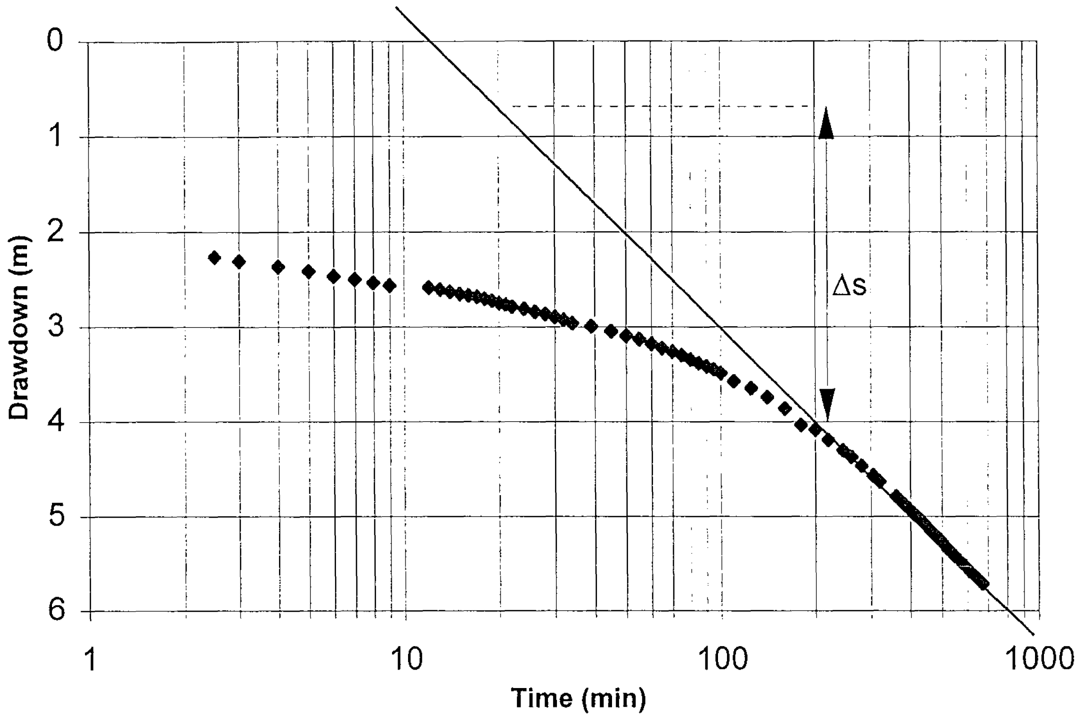
V-III-II: Well Hydrographs.


O31/115 Drawdown/Recovery
Drawdown (m)
0
1
2
3
4
5
6
0
500
1000
1500
2000
Time (min)
pump turned off at T=670 min)


O31/003 drawdown/Recovery
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Drawdown (m)
0
500
1000
1500
2000
Time (min)   (pump turned off at T=670 min)

V-III-III: Calculations.

O31/0115- Drawdown



$Q = 0.768\ m^3/min$
$\Delta s = 3.36\ m$

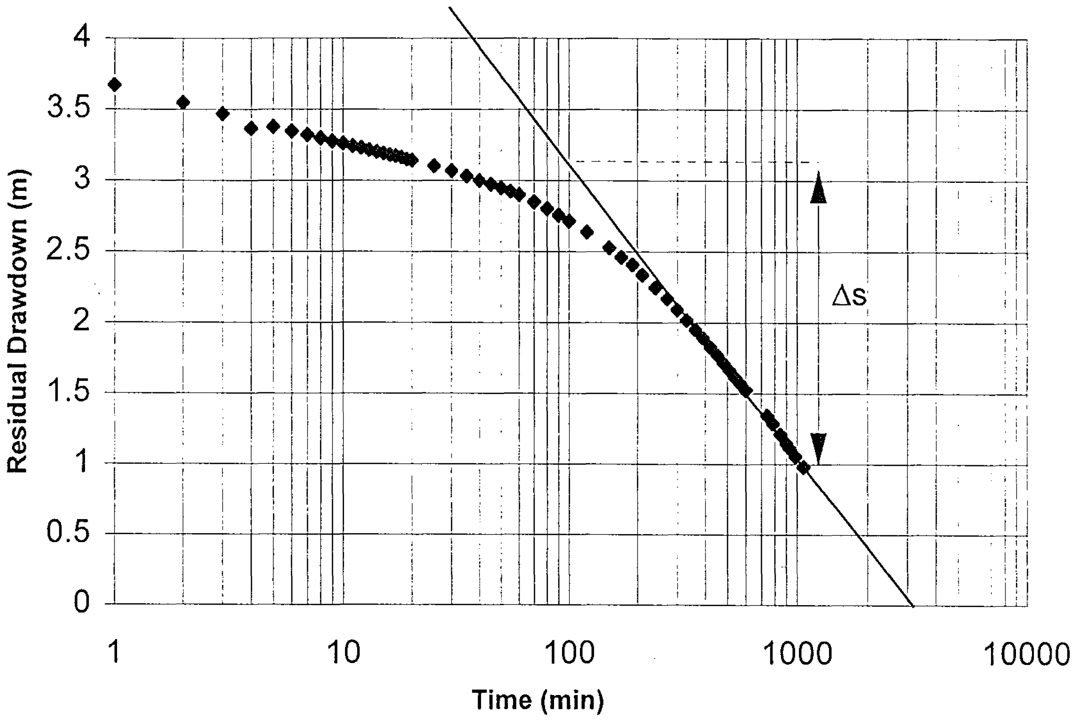
$$kD = \frac{2.3\ Q}{4\ \pi\ \Delta s}$$

$$= \frac{2.3 \times 0.768}{4 \times \pi \times 3.36}$$

$$= \underline{\underline{0.0414\ m^3/min/m}}$$

$$= \underline{\underline{0.4 \times 10^{-1}\ m^2/min}}$$

O31/0115 - Recovery



Q = 0.768 m^3/min
Δs = 3.1 m

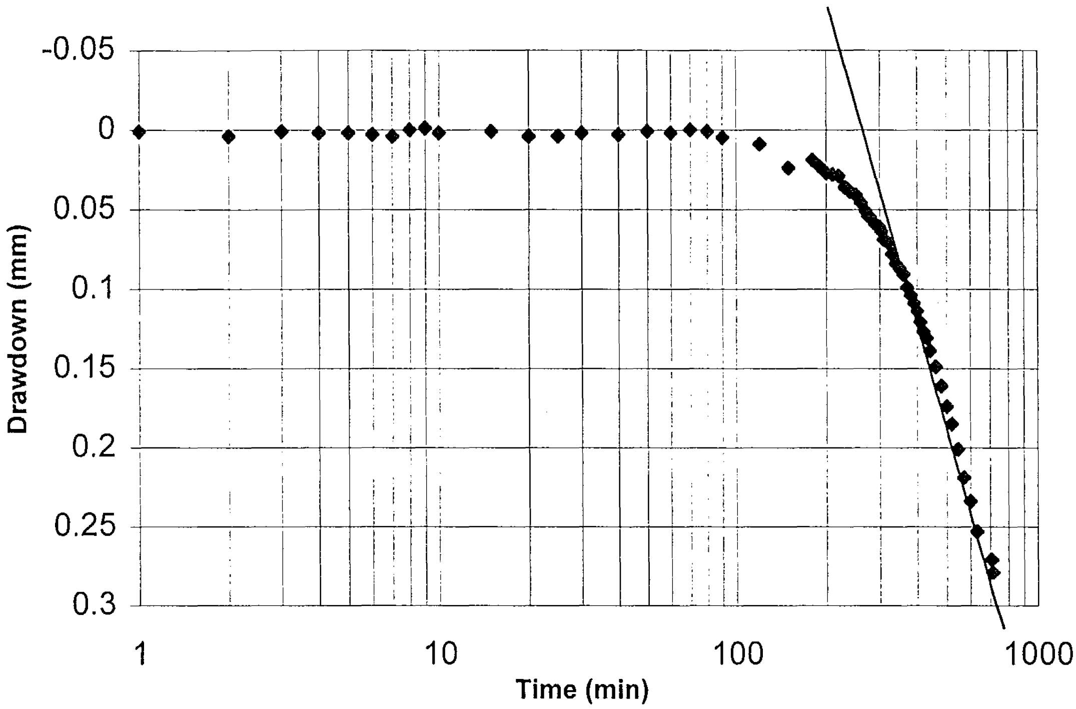
$$kD = \frac{2.3\ Q}{4\ \pi\ \Delta s}$$

$$= \frac{2.3 \times 0.768}{4 \times \pi \times 3.1}$$

$$= \underline{\underline{0.0449\ m^3/min/m}}$$

$$= \underline{\underline{0.45 \times 10^{-1}\ m^2/min}}$$

O31/003 Drawdown



$Q = 0.768\ m^3/min$

$\Delta s = 0.652\ m$

$t_0 = 260\ min$

$$kD = \frac{2.3\,Q}{4\,\pi\,\Delta s} = \frac{2.3 \times 0.768}{4 \times \pi \times 0.652} = \underline{\underline{0.2135\ m^3/min/m}} = \underline{\underline{0.21\ m^2/min}}$$

$$S = \frac{2.25\,kD\,t_0}{r^2} = \frac{2.25 \times 0.21 \times 260}{410^2} = \underline{\underline{0.000743}} = \underline{\underline{7.4 \times 10^{-4}}}$$

V-IV: Mt. Fyffe Road Pump Test.

INTRODUCTION

A constant rate discharge test was carried out on the Kaikoura District Councils alternate town supply well on Mt. Fyffe Road, between Schoolhouse Road and Postmans Road (Figure V.II). The pumped well (O31/204) penetrates Aquifer 2 and is dual screened at 16.24m to 19.24m and 23.36m to 26.36m within this aquifer. The well was pumped at a constant rate of 1.2m^3/min (1814.4m^3/day) from 12:12 on 4/7/95 until 12:00 on 5/7/95. Two observation wells were used to monitor the effects of the pumping, the first (O31/246) at a distance of 100m was only 5.6m deep and penetrated unconfined Aquifer 1, the second (O31/200), at a distance of 625m penetrated Aquifer 2. Drawdown and recovery of the water levels were measured manually for all wells, in addition to this well O31/200 has been used as a long term observation well and is fitted with a stevensons digital recorder.

A general decrease in water levels over the duration of the pumping and recovery observations was corrected by applying a time dependent correction factor to the data so that water levels at the end of the test were the same as they were to begin with. The correction factors used are listed with the relevant drawdown data.

DATA ANALYSIS

Before the test was undertaken the pumped well O31/204 was assumed to be fully confined, however, the response of well O31/246 in unconfined Aquifer 1 to the pumping has shown that Aquifer 2 is only semiconfined in this area, this is also indicated by the flattening of the drawdown curves.

The drawdown data for the pumped well (O31/204) was not used for analysis as small fluctuations in the pumping rate produced an erratic drawdown curve.

Values for aquifer transmissivity and storativity were determined from observation well O31/200 using the Jacobs' non-steady state confined solution, Waltons' matchpoint method for semi-confined aquifers and also the Superpump groundwater analysis/design program.

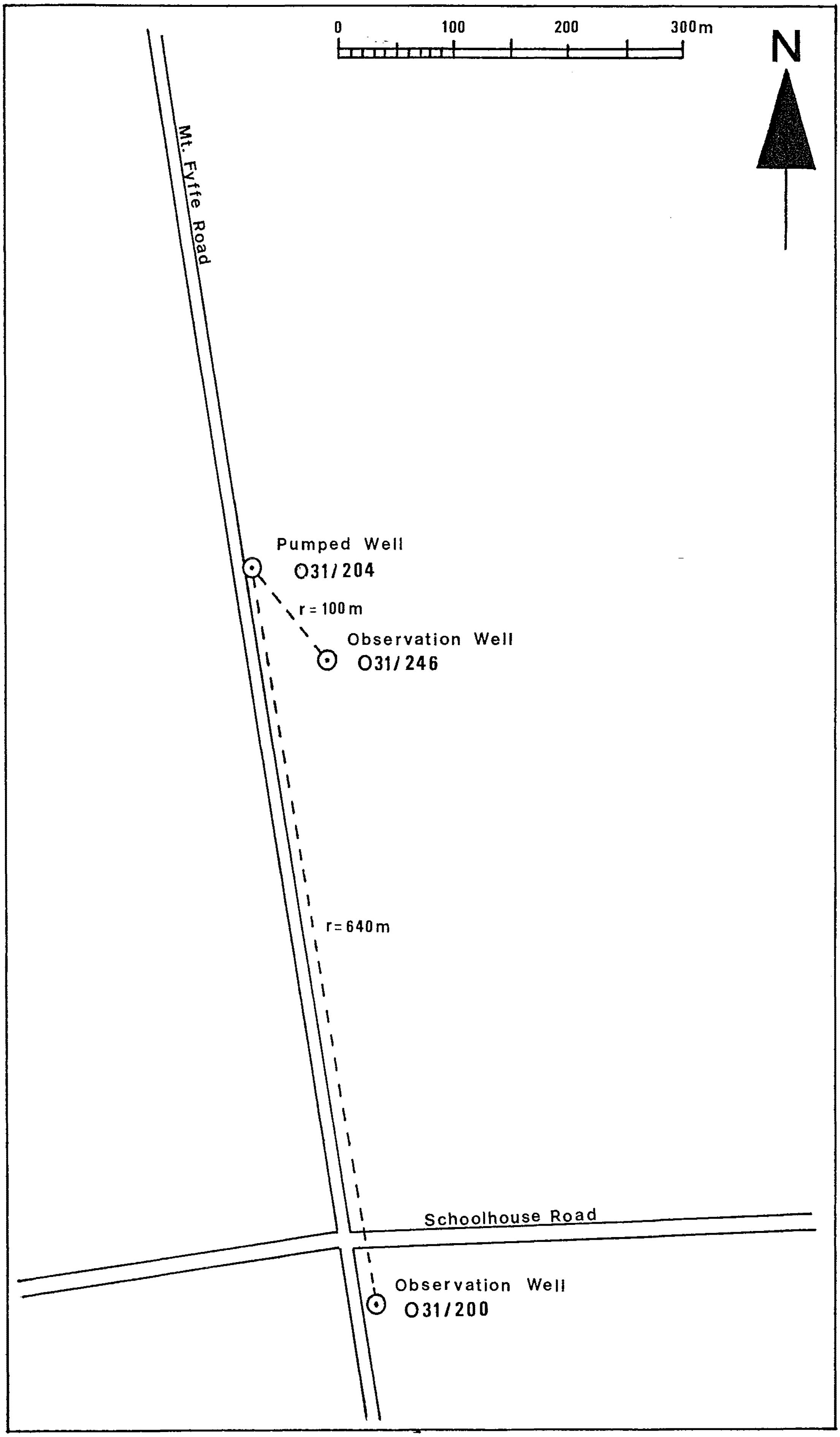


FIGURE V-II. Pump Test Location.

Examination of the drawdown and recovery curves for well O31/200 show the effect of delayed yield from the overlying sediments. The effect of delayed yield is to decrease the slope of the drawdown curve, this is due to water draining from the overlying sediments having the effect of a temporary recharge event. Once the drawdown in the overlying sediments is in equilibrium with the drawdown within the aquifer then the drawdown curve returns to its initial slope.

AQUIFER CHARACTERISTICS

The pump testing of well O31/204 has allowed the determination of the following aquifer characteristics:

Method of Analysis	**Transmissivity (m^3/min/m)**	**Storativity**	**Leakage coefficient**
Walton match point	1.73	2.34×10^{-4}	
Jacob unsteady state, confined	3.20	3.90×10^{-4}	
Superpump-leaky artesian	2.49	2.57×10^{-4}	4.75×10^{-4}

These characteristics are consistent with a moderately high yielding aquifer of semi-confined nature.

The aquifer characteristics obtained with the superpump program were then used to determine the drawdown just outside of the pumped well at a pumping rate of 25 l/s (Figure V-III). From this a value for well loss has been estimated at about 4m which indicates a very inefficient well, where well loss is the difference between the drawdown within the well casing itself and the drawdown within the aquifer immediately outside the well casing.

A maximum permissible drawdown of six meters was determined for well O31/204. This value was obtained by subtracting the lowest recorded water level (7m below ground surface) from the lowest allowable water level (upper surface of aquifer 2 confining layer, 13m below ground surface).

The long term drawdown for the well has been determined for a pumping rate of 25l/s and also the combined drawdown for the existing well and a second identical well at a radius of 5m (Figure V-IV). At low water levels with two wells pumping the maximum permissible drawdown would be exceeded within one days pumping, This is assuming that the second well displayed identical performance to the existing well. The long term sustained yield of the present well should be about 30 l/s and for dual wells should be around 20 l/s per well (40 l/s total). However, the drawdown vs pumping rate plot shown in Figure V-V suggests that theoretically the aquifer is capable of supporting a much higher long term pumping rate, up to 100 l/s for a well with 100% efficiency, suggesting that unsatisfactory well performance is the result of an inefficient well rather than a low yielding aquifer.

SUMMARY OF MAIN POINTS

- Well O31/204 penetrates an aquifer of semi-confined nature displaying values for aquifer transmissivity and storativity of:

  $$T = 2.49\ m^3/min/m$$

  $$S = 2.57 \times 10^{-4}$$

- The well has a sustained long term pumping rate of about 30 l/s, which theoretically could be as much as 100 l/s.

- The unsatisfactory performance of the well is likely to be due to its' inefficiency. Redevelopment could reduce well losses and enhance well performance.

- The semi-confined nature of the well enhances the possibility of water supply contamination, especially micro-biological and nitrate contamination derived from dairy effluent upgradient from the well.

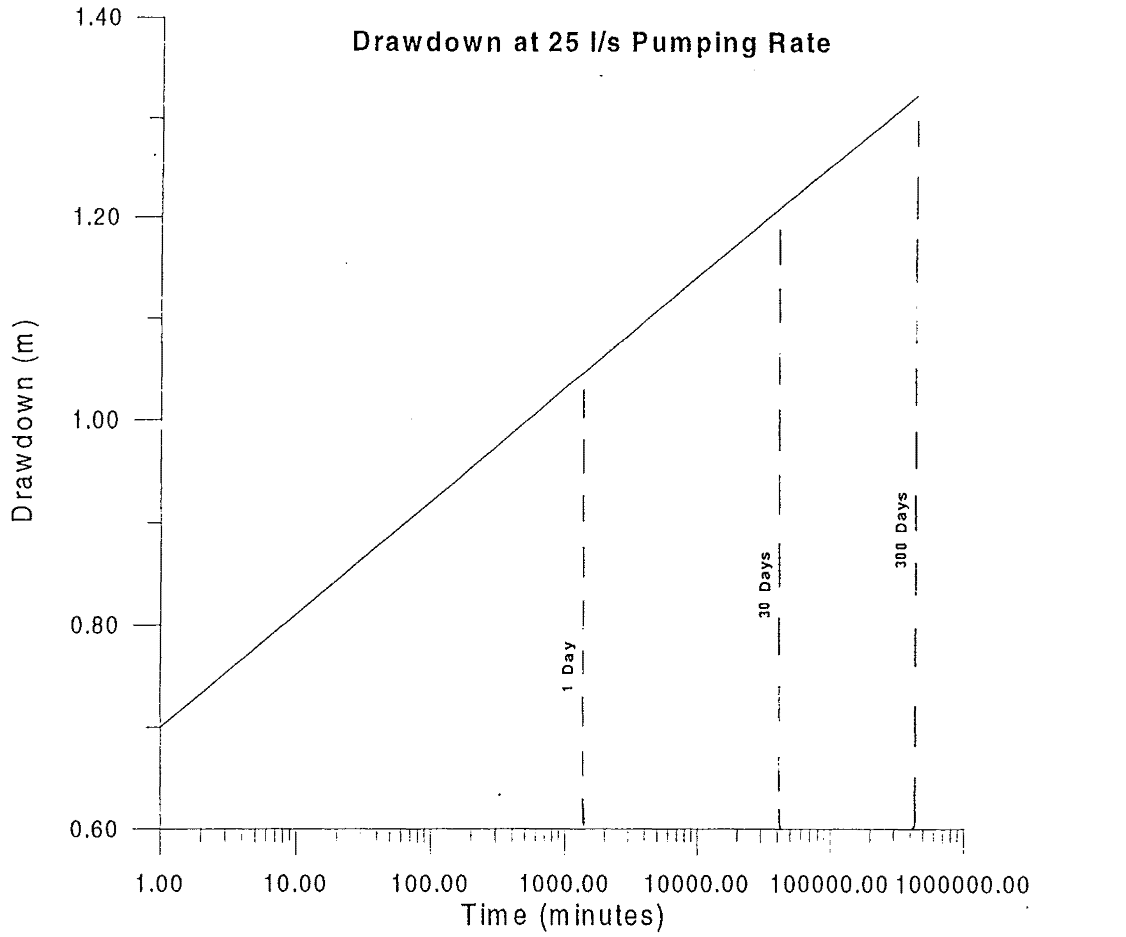


FIGURE V-III. Calculated drawdown within aquifer immediately adjacent to pumped well.

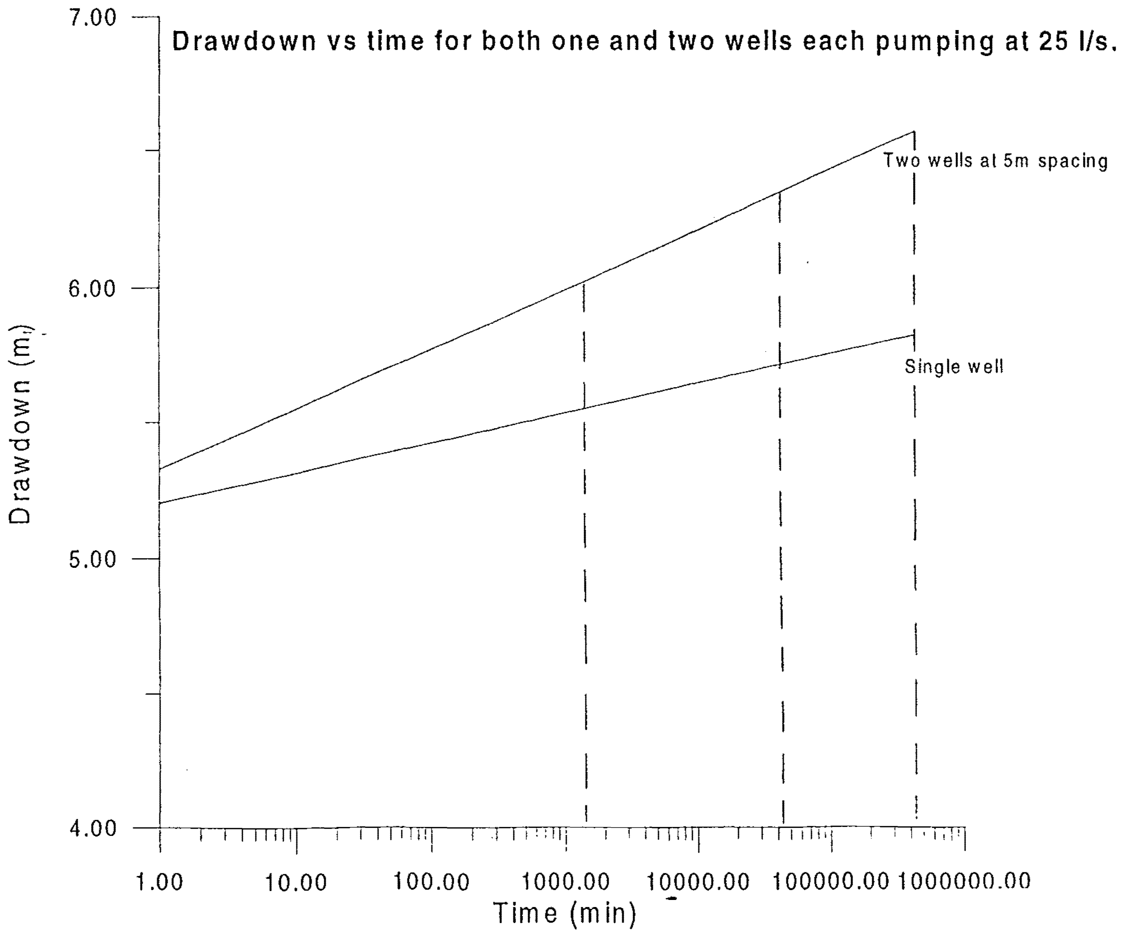


FIGURE V-IV. Drawdown for both single and dual wells pumping at 25l/s.

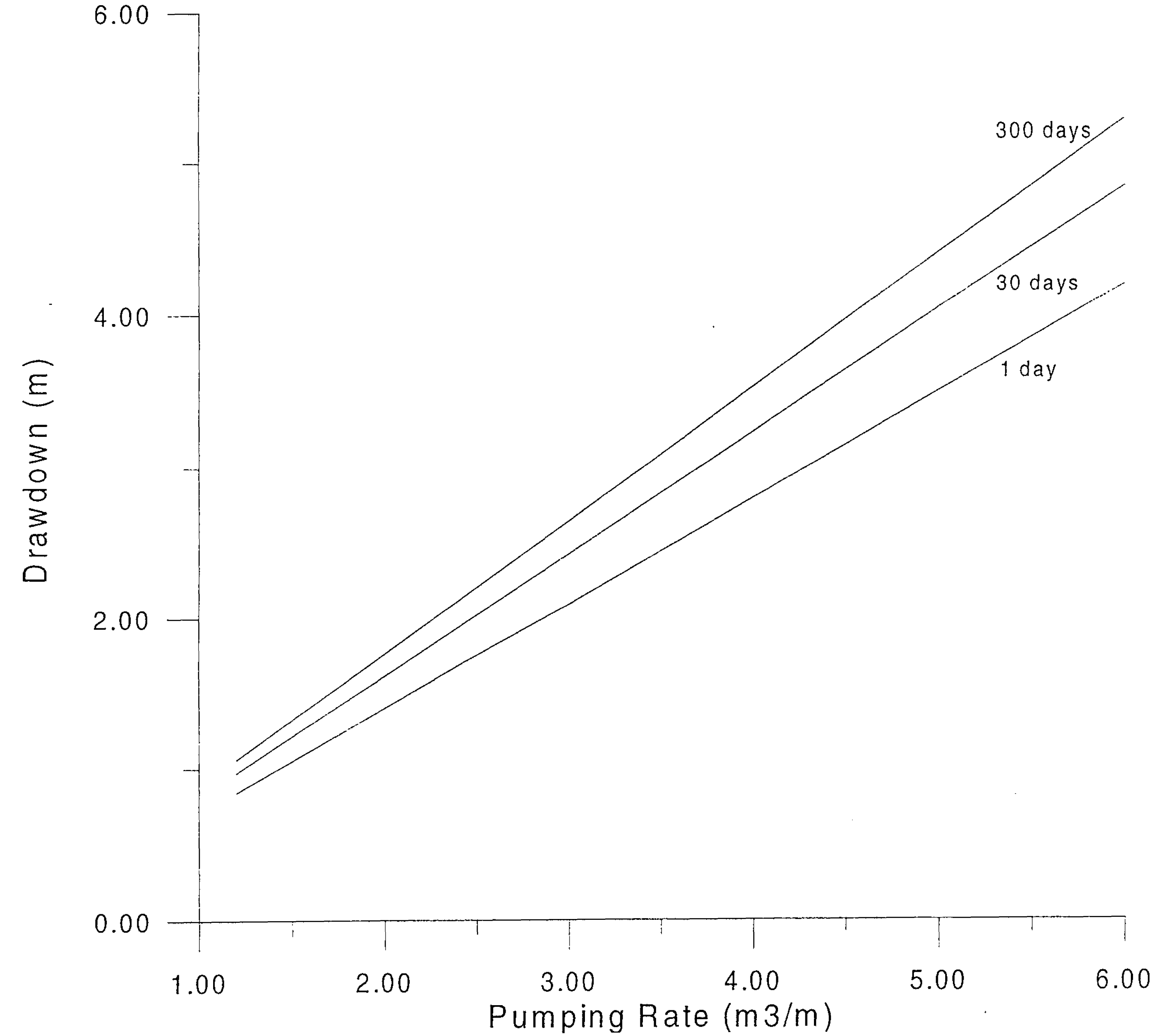


FIGURE V-V. Theoretical well performance.

V-IV-I: Pump Test Data.

MT. FYFFE ROAD PUMP TEST

PUMPED WELL - O31/204

Initial depth to water = 1.362m
Pump turned on at 12:12 on 4/7/95

Time since pumping started (min)	Depth to water (m)	Pumping rate (l/s)	Draw-down (m)	Correction factor (m)	Corrected drawdown (m)
0	1.362	21	0.000	0.000	0.000
1	5.499		4.137	0.000	4.137
2	5.750		4.388	0.000	4.388
3	5.845		4.483	0.000	4.483
4	5.870		4.508	0.000	4.508
5	5.881		4.519	0.000	4.519
6	5.892		4.530	0.000	4.530
7	5.900		4.538	0.000	4.538
8	-	18		0.000	
9	-			0.000	
10	5.880		4.520	0.000	4.520
15	6.412	21	5.050	0.000	5.050
17	6.475		5.113	0.000	5.113
18	6.500		5.138	0.000	5.138
19	6.516		5.154	0.000	5.154
21	6.535		5.173	0.000	5.173
22	6.540		5.178	0.000	5.178
26	6.535		5.173	0.000	5.173
30	6.540	21	5.168	0.000	5.168
35	6.526		5.164	0.001	5.163
40	6.527	20.5	5.165	0.001	5.164
50	6.780	21.5	5.418	0.001	5.417
55	6.600	21	5.238	0.001	5.237
60	6.495		5.133	0.001	5.132
70	6.482	20.5	5.120	0.001	5.119
80	6.622	21	5.260	0.001	5.259
90	6.668		5.308	0.001	5.307
100	6.689	21	5.327	0.002	5.325
111	6.663		5.301	0.002	5.299
120	6.665	21	5.303	0.002	5.301
130	6.658		5.296	0.002	5.294
150	6.647		5.285	0.002	5.283
180	6.650	21	5.288	0.003	5.285

210	6.647		5.285	0.003	5.282
240	6.648		5.286	0.004	5.282
270	6.656	21	5.294	0.004	5.290
300	6.653		5.291	0.005	5.286
360	6.625	21	5.263	0.006	5.257
470	6.630	21	5.268	0.008	5.260
530	6.625	21	5.263	0.009	5.254
590	6.618	21	5.256	0.010	5.246
650	6.627	21	5.267	0.011	5.256
710	6.623	21	5.261	0.011	5.250
770	6.785	21.5	5.423	0.012	5.411
830	6.725	21	5.363	0.013	5.350
890	6.690	21	5.328	0.014	5.314
950	6.690	21	5.328	0.015	5.313
1008	6.690	21	5.328	0.016	5.312
1073	6.710	21	5.348	0.017	5.331
1128	6.715	21.2	5.353	0.018	5.335
1188	6.715	21.2	5.353	0.019	5.334
1248	6.730	21.2	5.368	0.020	5.348
1308	6.720	21.2	5.358	0.021	5.337
1368	6.720	21.2	5.358	0.022	5.336
1428	6.710	21.2	5.348	0.023	5.325
Pump turned off at 12:00 on 5/7/95					
1428.5	2.732		1.370	0.023	1.347
1429	2.132		0.770	0.023	0.747
1429.5	1.964		0.602	0.023	0.579
1430	1.869		0.507	0.023	0.484
1431	1.764		0.402	0.023	0.379
1432	1.707		0.345	0.023	0.322
1433	1.672		0.310	0.023	0.287
1434	1.643		0.281	0.023	0.258
1435	1.622		0.260	0.023	0.237
1436	1.607		0.245	0.023	0.222
1437	1.592		0.230	0.023	0.207
1438	1.580		0.218	0.023	0.195
1444	1.535		0.173	0.023	0.150
1448	1.516		0.154	0.023	0.131
1453	1.502		0.140	0.023	0.117
1458	1.490		0.128	0.024	0.104
1463	1.485		0.123	0.024	0.099
1468	1.472		0.110	0.024	0.086
1473	1.465		0.103	0.024	0.079
1478	1.460		0.098	0.024	0.074
1483	1.455		0.093	0.024	0.069

1488	1.451	0.089	0.024	0.065
1498	1.447	0.085	0.024	0.061
1508	1.441	0.079	0.024	0.055
1518	1.437	0.075	0.025	0.050
1528	1.435	0.073	0.025	0.048
1538	1.433	0.071	0.025	0.046
1548	1.432	0.070	0.025	0.045
1563	1.426	0.064	0.025	0.039
1578	1.426	0.064	0.026	0.038
1593	1.423	0.061	0.026	0.035
1608	1.426	0.064	0.026	0.038
1638	1.425	0.063	0.026	0.037
1668	1.423	0.061	0.027	0.034
1698	1.420	0.058	0.027	0.031
1728	1.419	0.057	0.028	0.029
1758	1.421	0.059	0.028	0.031
1788	1.426	0.064	0.029	0.035
1848	1.422	0.060	0.030	0.030
1908	1.421	0.059	0.031	0.028
1968	1.420	0.058	0.032	0.026
2148	1.420	0.058	0.035	0.023
2628	1.414	0.052	0.043	0.009
2748	1.412	0.050	0.044	0.006
2988	1.410	0.048	0.048	0.000

OBSERVATION WELL - O31/200

Initial water level = 9.705 = +0.295m
Pump turned on at 12:12 on 4/7/95
r = 640m

Time sinc pumping started (min)	Depth to water (m)	Draw-down (m)	Correction factor (m)	Corrected drawdown (m)
0	9.708	0.00	0.000	0.000
3	9.708	0.50	0.039	0.461
7	9.709	1.00	0.090	0.910
8	9.709	1.50	0.103	1.397
8.5	9.710	2.50	0.110	2.390
9	9/711	3.50	0.116	3.384
10	9.712	4.00	0.129	3.871
10.5	9.712	4.50	0.135	4.365
11	9.713	5.50	0.142	5.358
11.5	9.714	6.50	0.148	6.352
12	9.715	7.50	0.155	7.345
12.5	9.716	8.50	0.161	8.339
13	9.718	10.00	0.168	9.832
13.5	9.719	11.00	0.174	10.826
14	9.720	12.00	0.181	11.819
14.5	9.720	12.50	0.187	12.313
15	9.721	13.50	0.193	13.307
15.5	9.722	14.50	0.200	14.300
16	9.723	15.50	0.206	15.294
17	9.724	16.50	0.219	16.281
18	9.726	18.50	0.232	18.268
19	9.728	20.00	0.245	19.755
20	9.729	21.50	0.258	21.242
21	9.731	23.50	0.271	23.229
22	9.732	24.50	0.284	24.216
23	9.734	26.00	0.297	25.703
28	9.739	31.50	0.361	31.139
33	9.747	39.50	0.425	39.075
43	9.753	45.50	0.554	44.946
48	9.757	49.50	0.619	48.881
58	9.764	56.00	0.748	55.252
68	9.769	61.50	0.877	60.623
78	9.773	65.50	1.006	64.494
93	9.778	70.50	1.199	69.301

108	9.783	75.50	1.392	74.108
123	9.785	77.50	1.586	75.914
138	9.787	79.50	1.779	77.721
154	9.789	81.50	1.986	79.514
168	9.791	83.50	2.166	81.334
198	9.795	87.50	2.553	84.947
228	9.797	89.50	2.940	86.560
258	9.799	91.50	3.327	88.173
288	9.800	92.50	3.713	88.787
318	9.802	94.50	4.100	90.400
348	9.804	96.50	4.487	92.013
368	9.806	98.00	4.745	93.255
408	9.807	99.50	5.261	94.239
463	9.809	101.50	5.970	95.530
498	9.810	102.50	6.421	96.079
528	9.810	102.50	6.808	95.692
558	9.812	104.50	7.195	97.305
588	9.812	104.50	7.581	96.919
618	9.813	105.50	7.968	97.532
648	9.814	106.50	8.355	98.145
708	9.815	107.50	9.129	98.371
768	9.816	108.50	9.902	98.598
828	9.822	114.50	10.676	103.824
888	9.823	115.50	11.449	104.051
948	9.824	116.50	12.223	104.277
1008	9.826	118.50	12.997	105.503
1068	9.828	120.50	13.770	106.730
1128	9.831	123.50	14.544	108.956
1188	9.834	126.50	15.317	111.183
1248	9.836	128.50	16.091	112.409
1308	9.836	128.50	16.865	111.635
1368	9.837	129.50	17.638	111.862
1428	9.838	130.00	18.386	111.614
Pump turned off at 12:00 on 5/7/95				
1428	9.838	130.00	18.386	111.614
1429	9.838	130.00	18.399	111.601
1430	9.838	130.00	18.412	111.588
1431	9.838	130.00	18.425	111.575
1432	9.838	130.00	18.438	111.562
1433	9.838	130.00	18.451	111.549
1434	9.838	130.00	18.463	111.537
1435	9.837	129.50	18.476	111.024
1436	9.836	128.50	18.489	110.011
1437	9.834	126.50	18.502	107.998

1438	9.833	125.50	18.515	106.985
1439	9.832	124.00	18.528	105.472
1440	9.830	122.50	18.541	103.959
1441	9.828	120.50	18.554	101.946
1442	9.826	118.50	18.567	99.933
1443	9.824	116.50	18.580	97.920
1444	9.823	115.00	18.592	96.408
1445	9.821	113.50	18.605	94.895
1446	9.820	112.50	18.618	93.882
1447	9.818	110.00	18.631	91.369
1448	9.816	108.50	18.644	89.856
1449	9.815	107.50	18.657	88.843
1450	9.813	105.50	18.670	86.830
1451	9.812	104.50	18.683	85.817
1452	9.810	102.50	18.696	83.804
1453	9.809	101.50	18.708	82.792
1458	9.803	95.50	18.773	76.727
1463	9.798	90.50	18.837	71.663
1468	9.793	85.50	18.902	66.598
1478	9.786	78.00	19.031	58.969
1488	9.781	73.00	19.160	53.840
1498	9.776	68.50	19.289	49.211
1508	9.772	64.50	19.418	45.082
1518	9.768	60.50	19.547	40.953
1528	9.765	57.50	19.675	37.825
1538	9.763	55.50	19.804	35.696
1548	9.761	53.50	19.933	33.567
1568	9.757	49.50	20.191	29.309
1588	9.755	47.50	20.449	27.051
1608	9.754	46.50	20.707	25.793
1638	9.752	44.50	21.094	23.406
1668	9.752	44.50	21.481	23.019
1728	9.750	42.50	22.254	20.246
1788	9.750	42.50	23.028	19.472
1908	9.750	42.50	24.575	17.925
2028	9.748	40.50	26.122	14.378
2148	9.746	38.50	27.669	10.831
2268	9.746	38.50	29.217	9.283
2388	9.746	38.50	30.764	7.736
2508	9.746	38.50	32.311	6.189
2628	9.746	38.50	33.858	4.642
2748	9.746	38.50	35.406	3.094
2868	9.747	37.50	36.953	0.547
2988	9.746	38.50	38.500	0.000

OBSERVATION WELL - O31/246

Initial depth to water = 0.83m
Pump turned on at 12:12 on 4/7/95
r = 100m

Time since pumping started (min)	Depth to water (m)	Draw-down (m)	Correction factor (m)	Corrected drawdown (m)
0	0.83	0	0.00	0.00
1	0.83	0	0.03	-0.03
2	0.83	0	0.06	-0.06
3	0.83	0	0.10	-0.10
4	0.83	0	0.13	-0.13
5	0.83	0	0.16	-0.16
6	0.83	0	0.19	-0.19
7	0.83	0	0.23	-0.23
8	0.83	0	0.26	-0.26
9	0.83	0	0.29	-0.29
10	0.83	0	0.32	-0.32
11	0.83	0	0.36	-0.36
12	0.83	0	0.39	-0.39
13	0.83	0	0.42	-0.42
14	0.83	0	0.45	-0.45
15	0.83	0	0.49	-0.49
20	0.835	5	0.65	4.35
25	0.84	10	0.81	9.19
30	0.83	0	0.97	-0.97
35	0.84	10	1.14	8.86
40	0.85	20	1.30	18.70
45	0.85	20	1.46	18.54
50	0.85	20	1.62	18.38
55	0.85	20	1.78	18.22
60	0.85	20	1.95	18.05
65	0.85	20	2.11	17.89
75	0.85	20	2.43	17.57
85	0.85	20	2.76	17.24
100	0.84	10	3.24	6.76
113	0.86	30	3.67	26.33
128	0.865	35	4.15	30.85
143	0.87	40	4.64	35.36
158	0.87	40	5.13	34.87
188	0.872	42	6.10	35.90

218	0.88	50	7.07	42.93
248	0.882	52	8.05	43.95
278	0.882	52	9.02	42.98
308	0.885	55	9.99	45.01
348	0.89	60	11.29	48.71
468	0.905	75	15.18	59.82
503	0.91	80	16.32	63.68
563	0.915	85	18.27	66.73
618	0.92	90	20.05	69.95
678	0.925	95	22.00	73.00
738	0.93	100	23.94	76.06
778	0.935	105	25.24	79.76
828	0.94	110	26.86	83.14
888	0.945	115	28.81	86.19
948	0.945	115	30.76	84.24
1008	0.95	120	32.70	87.30
1068	0.955	125	34.65	90.35
1128	0.965	135	36.60	98.40
1188	0.97	140	38.55	101.45
1248	0.972	142	40.49	101.51
1308	0.972	142	42.44	99.56
1368	0.975	145	44.39	100.61

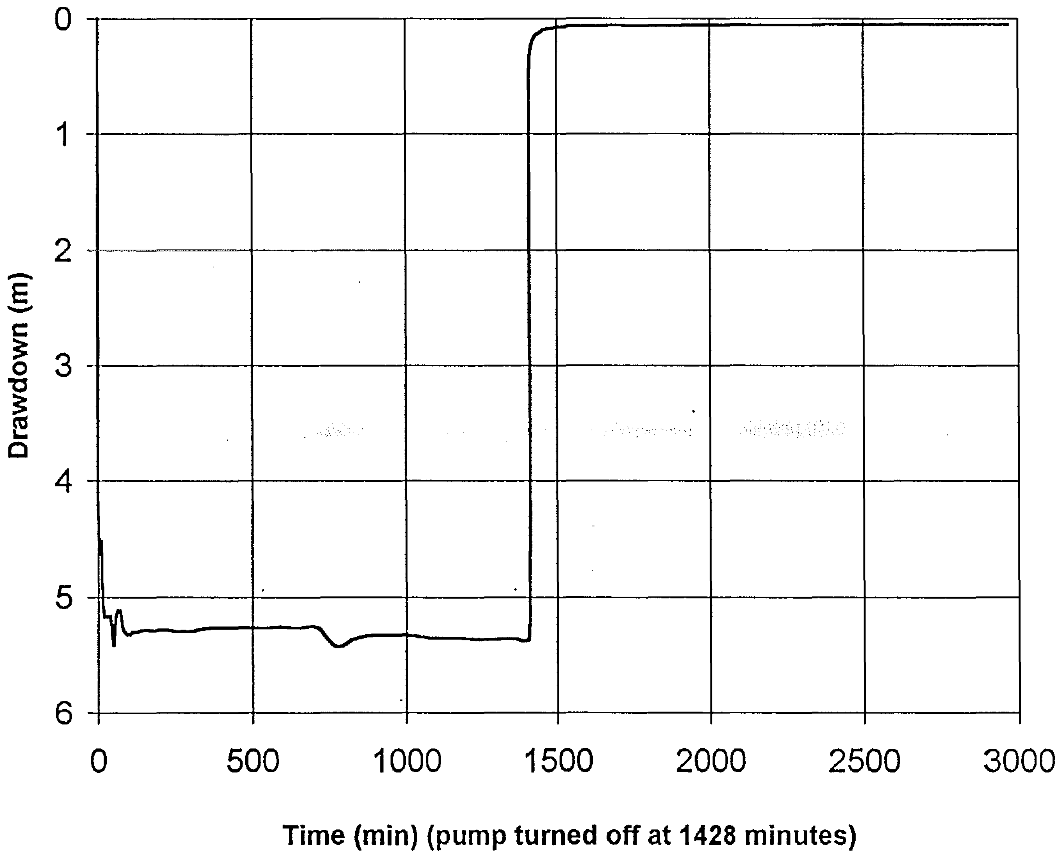
Pump turned off at 12:00 on 5/7/95

1368	0.98	145	44.39	100.61
1369	0.98	145	44.42	100.58
1370	0.98	145	44.45	100.55
1371	0.98	145	44.48	100.52
1372	0.98	145	44.52	100.48
1373	0.98	145	44.55	100.45
1374	0.975	140	44.58	95.42
1375	0.975	140	44.61	95.39
1376	0.97	135	44.64	90.36
1377	0.97	135	44.68	90.32
1378	0.97	135	44.71	90.29
1379	0.97	135	44.74	90.26
1380	0.97	135	44.77	90.23
1381	0.97	135	44.81	90.19
1382	0.97	135	44.84	90.16
1383	0.97	135	44.87	90.13
1384	0.97	135	44.90	90.10
1385	0.965	130	44.94	85.06
1386	0.965	130	44.97	85.03
1387	0.965	130	45.00	85.00
1388	0.965	130	45.03	84.97

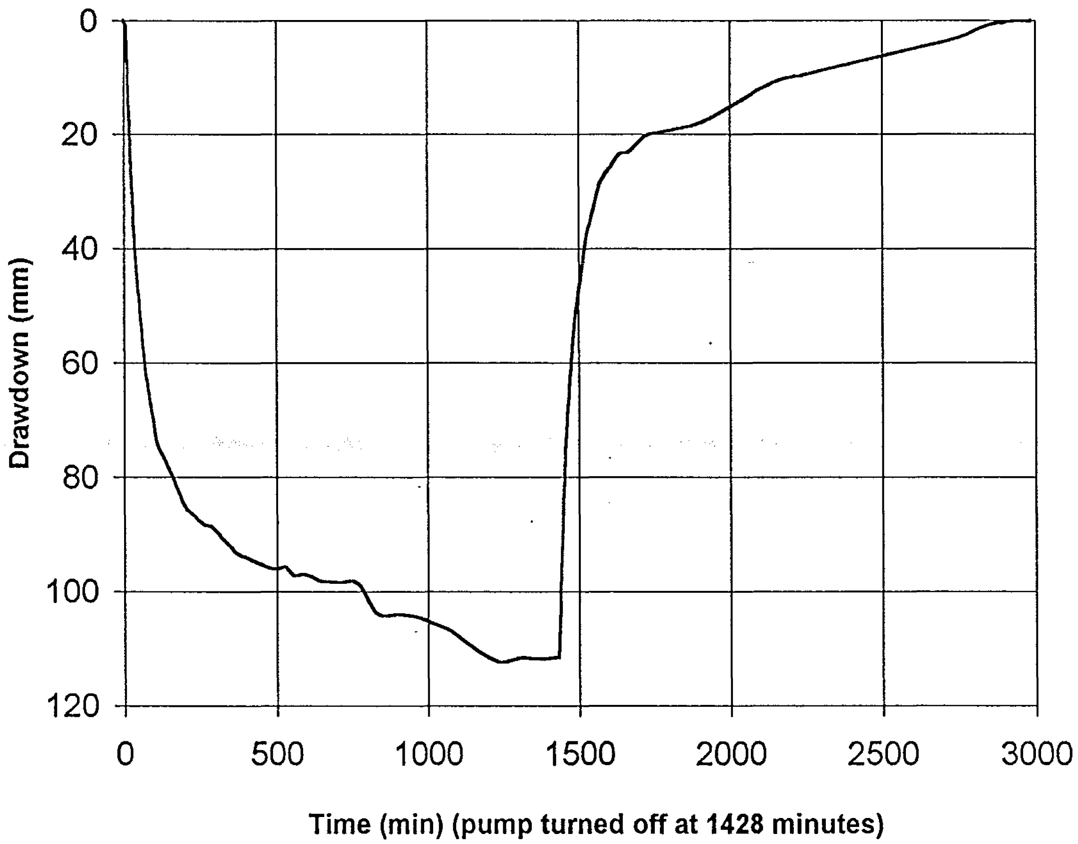
1393	0.965	130	45.20	84.80
1398	0.96	125	45.36	79.64
1403	0.96	125	45.52	79.48
1408	0.96	125	45.68	79.32
1413	0.955	120	45.85	74.15
1423	0.955	120	46.17	73.83
1433	0.955	120	46.49	73.51
1443	0.95	115	46.82	68.18
1453	0.95	115	47.14	67.86
1463	0.95	115	47.47	67.53
1473	0.95	115	47.79	67.21
1483	0.95	115	48.12	66.88
1503	0.945	110	48.77	61.23
1523	0.945	110	49.41	60.59
1543	0.945	110	50.06	59.94
1578	0.943	108	51.20	56.80
1613	0.942	107	52.33	54.67
1638	0.942	107	53.15	53.85
1668	0.942	107	54.12	52.88
1698	0.94	105	55.09	49.91
1728	0.94	105	56.07	48.93
1788	0.94	105	58.01	46.99
1848	0.937	102	59.96	42.04
1908	0.935	100	61.91	38.09
2088	0.935	100	67.75	32.25
2568	0.93	95	83.32	11.68
2688	0.93	95	87.21	7.79
2928	0.937	102	95.00	7.00

V-IV-II: Well Hydrographs.

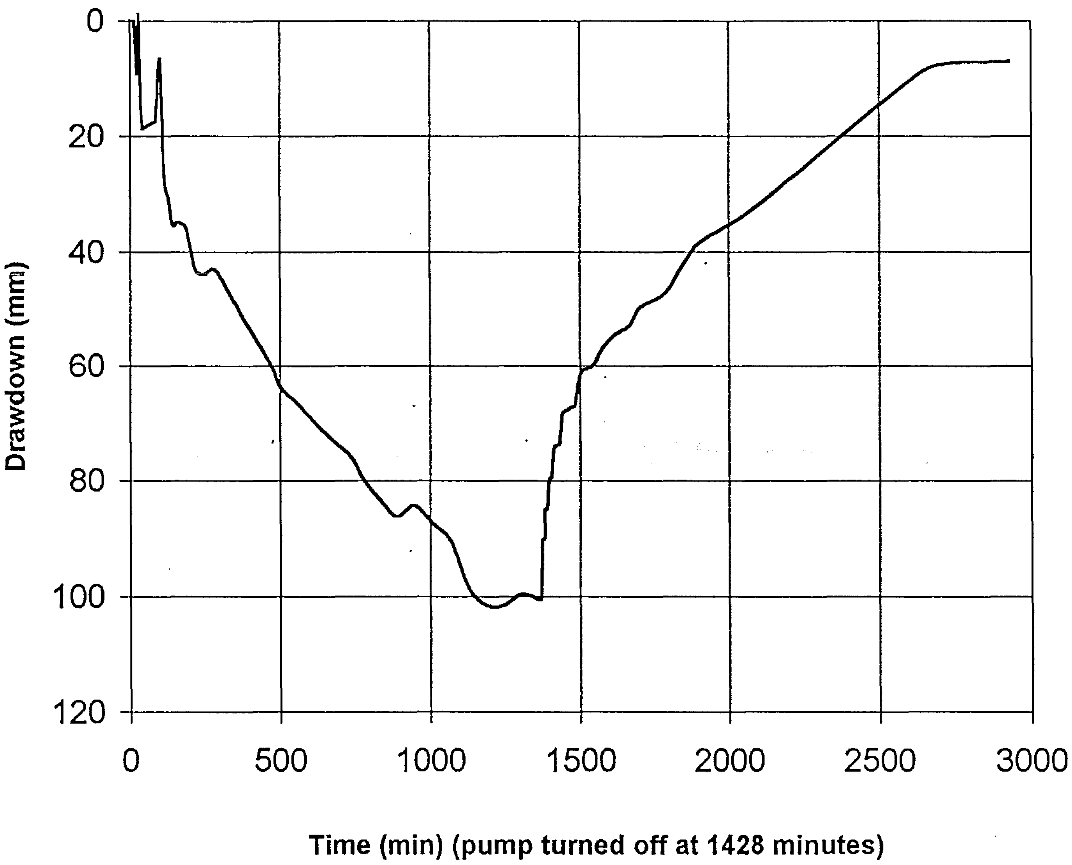
O31/204 Drawdown/Recovery



O31/200 Drawdown/Recovery

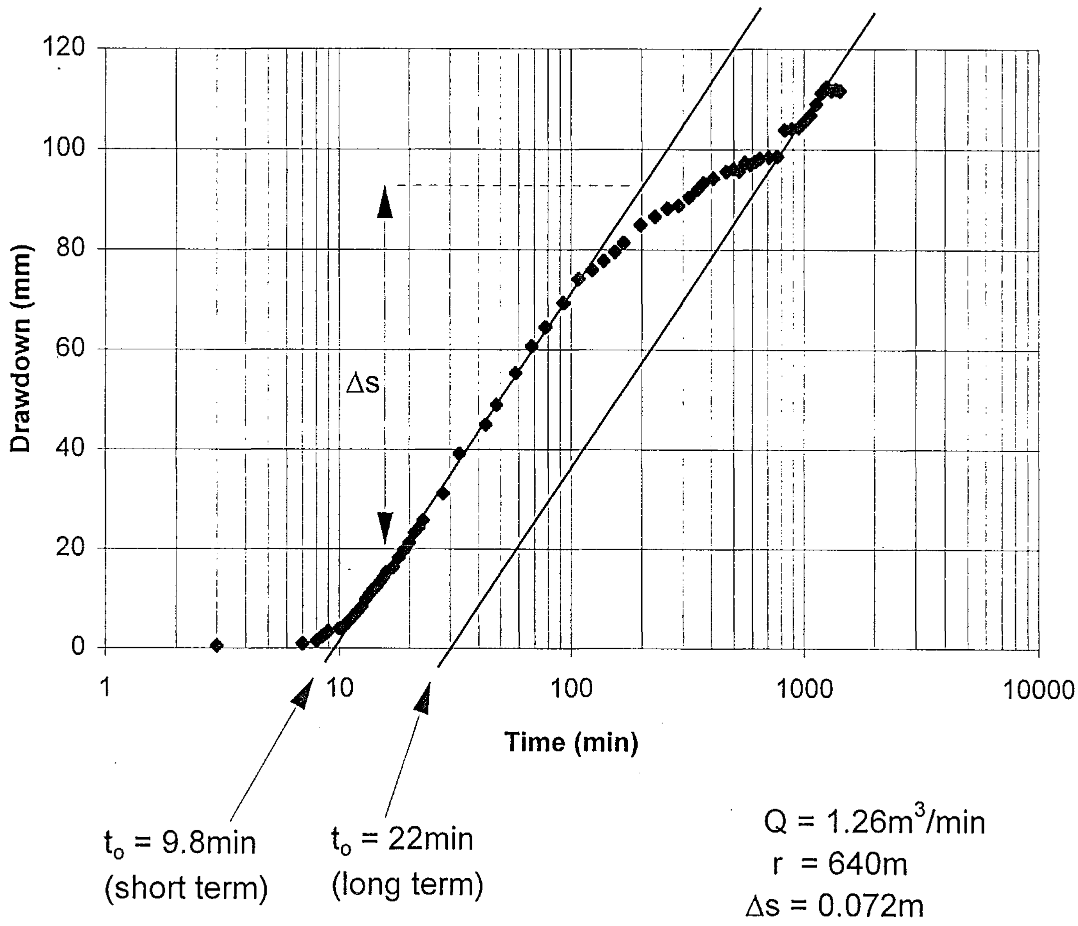


031/246 Drawdown/Recovery



V-IV-III: Calculations

O31/200 Drawdown



$$kD = \frac{2.3\,Q}{4\pi\Delta s}$$

$$= \frac{2.3 \times 1.26}{4\pi \times 0.072}$$

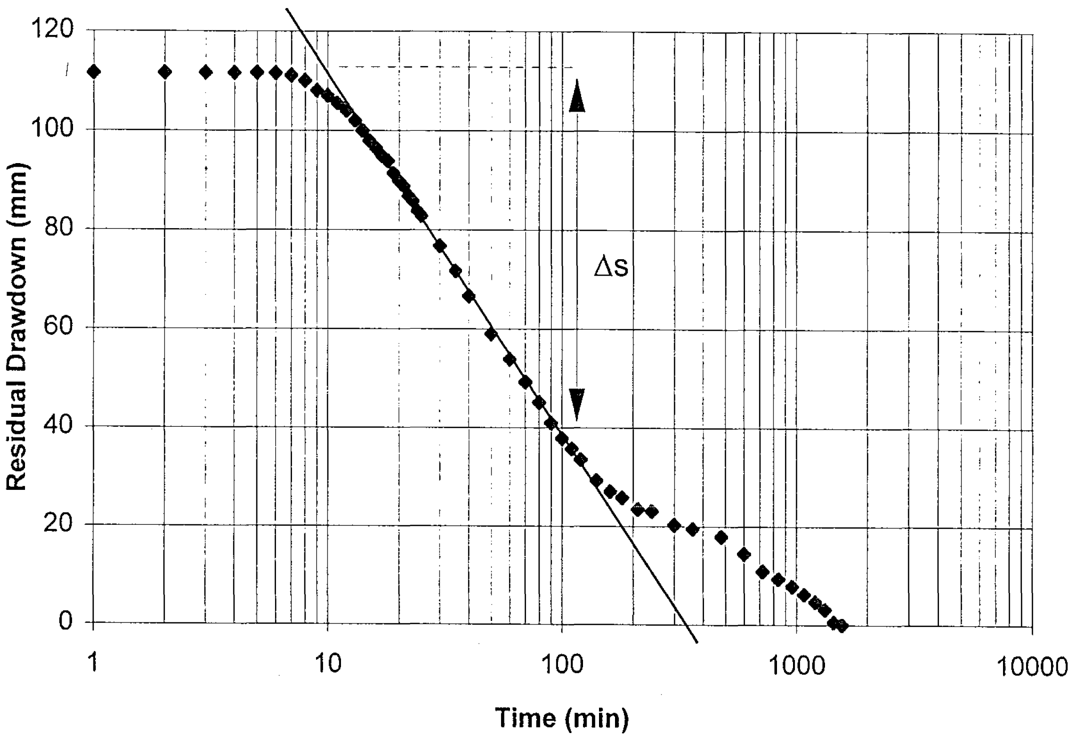
$$= \underline{\underline{3.2\ m^3/min/m}}$$

$$S = \frac{2.25\ kD\ t_o}{r^2}$$

$$= \frac{2.25 \times 3.2 \times 22}{640^2}$$

$$= \underline{\underline{3.9 \times 10^{-4}}}$$

O31/200 Recovery



$Q = 1.26\ m^3/min$
$r = 640\ m$
$\Delta s = 0.072\ m$

$$kD = \frac{2.3\ Q}{4\ \pi\ \Delta s}$$

$$= \frac{2.3 \times 1.26}{4\ \pi \times 0.072}$$

$$= \underline{\underline{3.2\ m^3/min/m}}$$

APPENDIX VI: Streamgauging Data.

Site No.	Creek / River	Location/ comment	O/31 Grid-Ref.	Stream Flow (l/s) 13-15/10/80	16-17/2/81	Stream Flow (l/s) 8-10/2/95
1	Kowhai River	gorge	650-730	3227	947	1335
2	"	Postmans Rd	677-713	3058	412	1123
3	"	Middle Ford	611-687	2462	113	857
4	"	S.H.1 Bridge	620-656	2553	236	993
5	Warrens Creek	Red Swamp Rd	624-685	94	70	50
6	"	Mt. Fyffe Rd	6470-6815	178	193	105
7	"	above Lyell Confl.	6575-6810	260	276	220
8	Lyell Creek	R.B. Mill Road	6415-6960	56	54	31
9	"	L.B. Mt. Fyffe Rd	6415-7010	75	57	26
10	"	Mill Rd	6590-6985	247	211	141
11	"	d/s Warrens confl.	658-680	576	439	346
12	Middle Creek	Postmans Rd	6145-7165	80	0	11
13	(Coles Creek)	Red Swamp Rd	617-705	5	15	12
14	Middle Creek	Mt Fyffe Rd	640-707	35	85	11
15	(drain)	Schoolhouse Rd	642-710	18	127	71
16	(Luke CreeK)	Schoolhouse Rd	649-711	73	179	51
17	Middle Creek	S.H. 1	6590-7065	253	467	209
18	Waimangarara	S.H. 1	6575-7165	39	60	18
19	"	Mouth	671-717	-	-	116
20	Harnetts Creek	Bay Paddock Rd	667-739	36	0	2
21	"	Beach Rd	674-725	14	25	0
22	Hapuku River	below Long Ck.	673-775	2175	861	1461
23	Puhi Puhi		691-780	1545	465	1345
24	Hapuku	Mouth	P31/708-754	3672	1611	2798
25	Waimangarara	Below KDC intake	636-748	246	119	106
26	Luke Creek	Below tributary	622-742	-	-	40

APPENDIX VII: Isotopic Data.

Source; Brown and Taylor (1974)

SITE	Grid-Ref S49/	DATE	O	D	T	DEPTH
Kowhai River	881 957	18.12.72	-9.11	-60.6	21.6	
"	883 958	12.4.73	-8.73	-55.9		
"	868 968	21.6.73	-8.8			
"	882 257	18.9.73	-9.29			
"	868 969	22.10.73	-9.25			
Hapuku River	998 024	18.12.72	-9.19	-58.2	22.4	
"	997 024	27.9.73	-9.23			
"	"	23.10.73	-9.8			
Puhi Puhi River	998 026	27.9.73	-7.91			
"	"	23.10.73	-8.17			
Hapuku River	001 023	11.4.73	-8.01			
"	999 023	18.9.73	-8.69			
Kahutara River	878 878	18.6.73	-7.94			
"	"	18.9.73	-8.51			
"	"	23.10.73	-7.98			
O31/0116	932 924	12.4.73	-8.18	-53.3		
O31/0001	963 918	12.4.73	-7.37	-46.9	17.4	8
O31/0110	943 972	30.8.72	-7.11	-42.8	18.7	9
O31/0104	987 996	30.8.72	-6.66	-41.5	18.4	14
O31/0121	963 970	18.6.73	-7.11			12
"	959 972	26.10.73	-7.23			14
O31/0113	897 961	12.4.73	-8.53	-53.6		8
O31/0114	924 958	19.9.73	-7.99			15
O31/0112	968 983	12.4.73	-5.92	-37.1		13
"	"	12.10.73	-6.4			13
O31/0037	898 962	23.10.72	-8.1		14.8	17
O31/0097	917 951	18.9.73	-8.73			24
O31/0036	919 949	18.9.73	-9.08			24
O31/0109	923 946	29.8.72	-8.81	-55.4	21.3	27
O31/0053	927 959	12.4.73	-9.01			29
O31/0086	916 937	12.4.73	-9.37	-63	0.43	25
O312/0058	924 922	19.9.73	-9.48			26
O31/0091	922 936	24.6.71	-9.36		0.93	22
O31/0085	935 939	12.4.73	-9.49	-62.1	1.6	28
O31/0090	957 931	30.8.72	-9.45	-59.9	0.27	25
"	"	11.4.73			0.31	25
O31/0004	957 930	23.10.73	-9.82		0.1	24
O31/0003	966 946	19.6.70	-8.31	-54.7	3.8	24
"	"	18.9.73	-7.44			24
"	"	23.10.73	-8.37		2.2	24

APPENDIX VIII: Piezometric Data.

VIII-I: AQUIFER 1 PIEZOMETRIC SURVEY

Summer (1/2/95)

Well # (O31/)	Grid-Ref. (O31-)	Reduced level (m)	Depth to Water (m)	Reduced water level (m)
3	663 703	8.50	1.24	9.75
7	695 745	6.00	4.80	1.20
26	6135 6900	55.00	1.90	53.10
30	592 713	107.79	8.50	99.29
50	601 649	7.00	3.40	3.60
52	614 661	18.00	4.80	13.20
55	649 696	24.00	2.69	21.31
88	627 658	7.62	2.90	4.72
93	584 643	7.00	3.25	3.75
95	600 650	9.79	6.33	3.46
96	606 651	9.00	3.89	5.11
99	698 753	9.14	0.96	8.18
101	6610 7285	39.60	dry	-
105	587643	7.00	6.35	-
106	588 642	7.00	4.74	2.26
110	637 720	45.01	dry	-
112	663 733	36.50	-	-
115	662 699	8.07	4.24	3.83
118	600 711	91.43	10.40	81.03
122	601 713	89.72	6.37	83.35
127	694 765	60.00	2.62	57.38
128	605 652	8.82	4.56	4.26
139	588 647	7.00	4.24	2.36
141	595 715	99.64	dry	-
142	602 686	84.68	7.79	76.89
145	624 657	7.28	2.34	4.94
146	620 664	29.85	2.86	26.99
171	611 697	63.09	12.18	50.91
216	595 682	68.00	8.31	59.69
218	611 635	63.00	9.20	53.80
219	628 661	8.41	3.28	5.13
221	6105 6520	9.00	4.92	4.08

222	595 671	55.00	1.26	53.74
223	5945 6710	55.00	0.80	54.20
224	595 676	55.00	1.84	53.16
225	624 683	35.40	1.05	34.35
226	630 702	39.86	3.34	36.52
227	583 643	12.00	3.56	8.44
231	5839 6383	7.00	2.46	4.64
232	5840 6385	7.00	2.74	4.26
233	5840 6388	7.00	2.86	4.14
234	5841 6390	7.00	2.74	4.26
238	699 746	5.58	3.50	2.08
240	698 747	6.32	2.80	3.52
246	637 714	36.53	3.82	32.71
247	624 589	39.97	4.43	35.54
248	628 688	34.37	0.51	33.86
249	663 713	9.57	1.88	7.69
250	645 696	21.12	1.07	20.05
252	658 705	9.43	2.50	6.93
253	659 714	12.27	1.80	10.47
255	659 725	30.41	1.36	29.05
256	664 724	21.65	5.35	16.30
257	670 722	8.79	5.56	3.23
258	663 705	7.85	1.98	5.87
Harnett	653 680	6.86	1.87	4.99
Smith	686 750	55.48	12.56	42.92
Anderson	6170 6655	16.00	1.33	14.67
Hutcheson	613 685	52.73	3.80	48.93
T.J.Boyd	658 714	22.00	1.96	20.04

VIII-II: AQUIFER 1 PIEZOMETRIC SURVEY

Winter (29/6/95)

Well # (O31/)	Grid-Ref. (O31-)	Reduced level (m)	Depth to Water (m)	Reduced water level (m)
3	663 703	8.50	(+)1.56	10.06
7	695 745	6.00	4.24	1.76
26	6135 6900	55.00	0.31	54.69
30	592 713	107.79	5.52	102.27
50	601 649	7.00	2.06	4.94
52	614 661	18.00	3.55	14.45
55	649 696	24.00	1.50	22.50
88	627 658	7.62	0.75	6.87
93	584 643	7.00	3.18	3.82
95	600 650	9.79	4.10	5.69
96	606 651	9.00	2.50	6.50
99	698 753	9.14	0.67	8.47
101	6610 7285	39.60	0.44	39.16
105	587643	7.00	3.52	3.48
106	588 642	7.00	3.94	3.06
110	637 720	45.01	0.69	44.32
112	663 733	36.50	2.80	33.70
115	662 699	8.07	0.00	8.07
118	600 711	91.43	4.56	86.87
122	601 713	89.72	1.10	88.62
127	694 765	60.00	2.66	57.34
128	605 652	8.82	3.27	5.55
139	588 647	7.00	3.07	3.93
141	595 715	99.64	0.36	99.28
142	602 686	84.68	6.58	78.10
145	624 657	7.28	1.60	5.68
146	620 664	29.85	2.85	27.00
171	611 697	63.09	5.08	58.01
216	595 682	68.00	7.22	60.78
218	611 635	63.00	7.20	55.80
219	628 661	8.41	0.25	8.16
221	6105 6520	9.00	3.65	5.35
222	595 671	55.00	0.30	54.70
223	5945 6710	55.00	0.00	55.00
224	595 676	55.00	0.40	54.60

225	624 683	35.40	0.71	34.69
226	630 702	39.86	(+)0.2	40.06
227	583 643	12.00	3.53	8.47
231	5839 6383	7.00	2.00	5.00
232	5840 6385	7.00	1.40	5.60
233	5840 6388	7.00	1.50	5.50
234	5841 6390	7.00	1.40	5.60
238	699 746	5.58	3.14	2.44
240	698 747	6.32	2.50	3.82
246	637 714	36.53	0.96	35.57
247	624 589	39.97	0.60	39.37
248	628 688	34.37	(+).05	34.42
249	663 713	9.57	1.31	8.26
250	645 696	21.12	0.22	20.90
252	658 705	9.43	1.50	7.93
253	659 714	12.27	0.70	11.57
255	659 725	30.41	0.32	30.09
256	664 724	21.65	0.24	21.41
257	670 722	8.79	1.92	6.87
258	663 705	7.85	1.38	6.47
Harnett	653 680	6.86	0.71	6.15
Smith	686 750	55.48	0.80	54.68
Anderson	6170 6655	16.00	0.65	15.35
Hutcheson	613 685	52.73	2.10	50.63
T.J.Boyd	658 714	22.00	0.85	21.15

VIII-III:AQUIFER 2 PIEZOMETRIC SURVEY

Summer (2/2/95)

Well # (O31/)	Grid-Ref. (O31-)	Reduced level (m)	Depth to Water (m)	Reduced water level (m)
6	614696	48.10	16.66	31.44
15	646687	13.00	16.00	-3.00
28	617690	55.00	12.50	42.50
29	620691	55.00	13.05	41.95
90	655685	6.70	(+)0.31	7.01
107	624703	39.60	13.67	25.93
108	624700	50.10	11.16	38.94
121	659721	17.49	2.05	15.44
125	625709	53.30	19.62	33.68
138	647716	41.89	1.91	39.98
155	616657	15.18	5.56	9.62
156	657684	7.50	(+)1.21	8.71
158	610714	76.65	7.62	69.03
169	614666	20.00	6.50	13.50
170	617705	63.00	24.99	38.01
173	606681	60.00	17.42	42.58
196	602680	56.00	18.05	37.95
197	60156800	58.00	18.60	39.40
199	648678	10.98	1.96	9.02
200	640707	30.31	1.69	28.62
204	637715	38.82	5.49	33.33
206	605714	84.88	5.80	79.08
210	608651	9.00	3.89	5.11
212	610718	93.94	8.50	85.44
213	644696	22.18	2.83	19.35
215	604716	94.92	3.12	91.80
260	622717	65.25	13.24	52.01
261	628708	47.36	11.61	35.75
HARNETT	650690	8.40	1.22	7.18

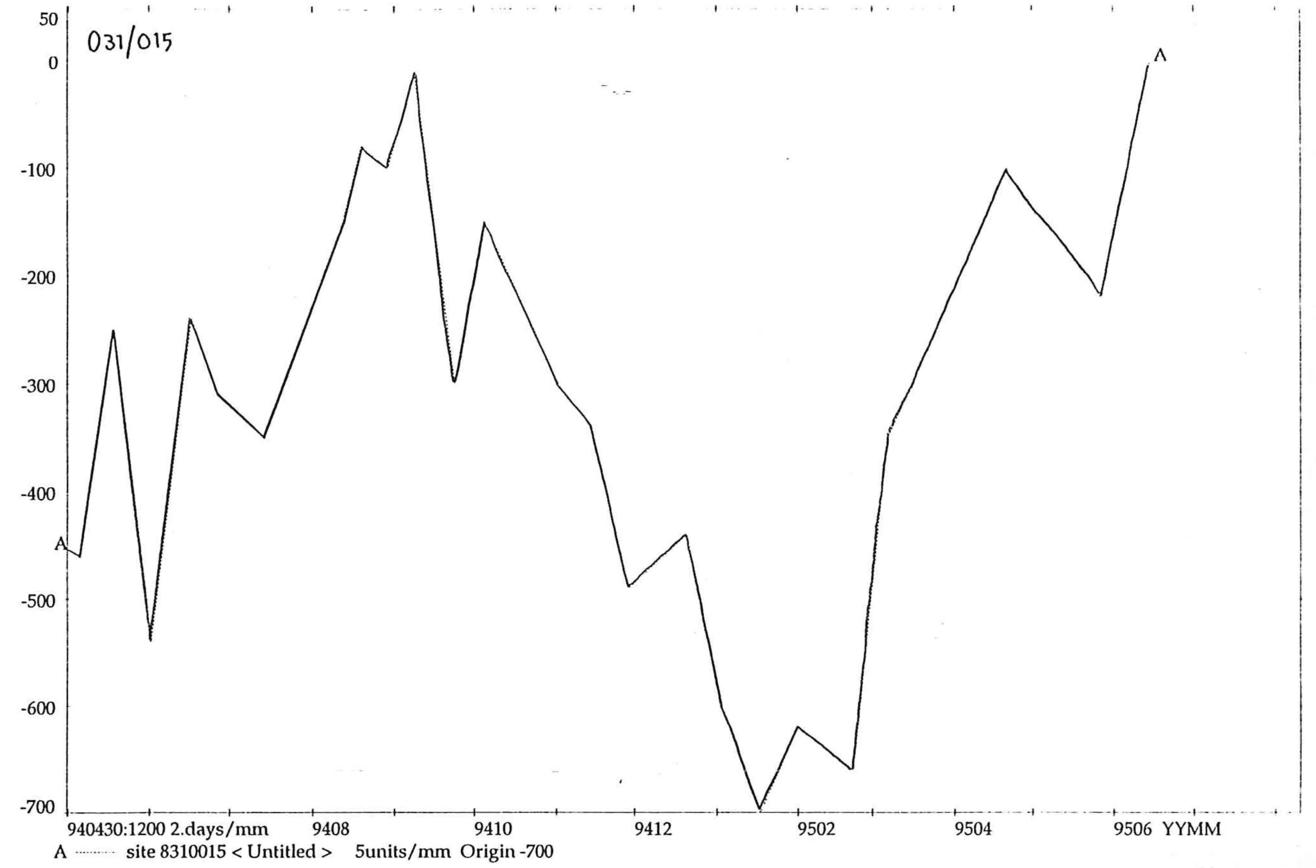
VIII-IV: AQUIFER 2 PIEZOMETRIC SURVEY

Winter (28/6/95)

Well # (O31/)	Grid-Ref. (O31-)	Reduced level (m)	Depth to Water (m)	Height a.s.l. (m)
6	614696	48.10	8.45	39.65
15	646687	13.00	0.00	13.00
28	617690	55.00	0.00	55.00
29	620691	55.00	(+)0.4	59.00
90	655685	6.70	(+)0.5	7.20
107	624703	39.60	5.43	34.17
108	624700	50.10	3.07	47.03
121	659721	17.49	(+)1	18.49
125	625709	53.30	14.40	38.90
138	647716	41.89	(+)0.26	42.15
155	616657	15.18	4.48	10.70
156	657684	7.50	(+)1.52	9.02
158	610714	76.65	2.10	74.55
169	614666	20.00	4.50	15.50
170	617705	63.00	15.10	47.90
173	606681	60.00	11.53	48.47
196	602680	56.00	11.42	44.58
197	60156800	58.00	13.34	44.66
199	648678	10.98	1.10	9.88
200	640707	30.31	(+)0.35	30.36
204	637715	38.82	1.45	37.37
206	605714	84.88	0.85	84.03
210	608651	9.00	2.87	6.13
212	610718	93.94	1.03	92.91
213	644696	22.18	2.08	20.10
215	604716	94.92	1.75	93.17
260	622717	65.25	(+)1	66.25
261	628708	47.36	7.60	39.76
HARNETT	650690	8.40	0.20	8.20

APPENDIX IX: Well Hydrographs

IX-I: Manual Observation Wells


031/015
50
0
-100
-200
-300
-400
-500
-600
-700
A
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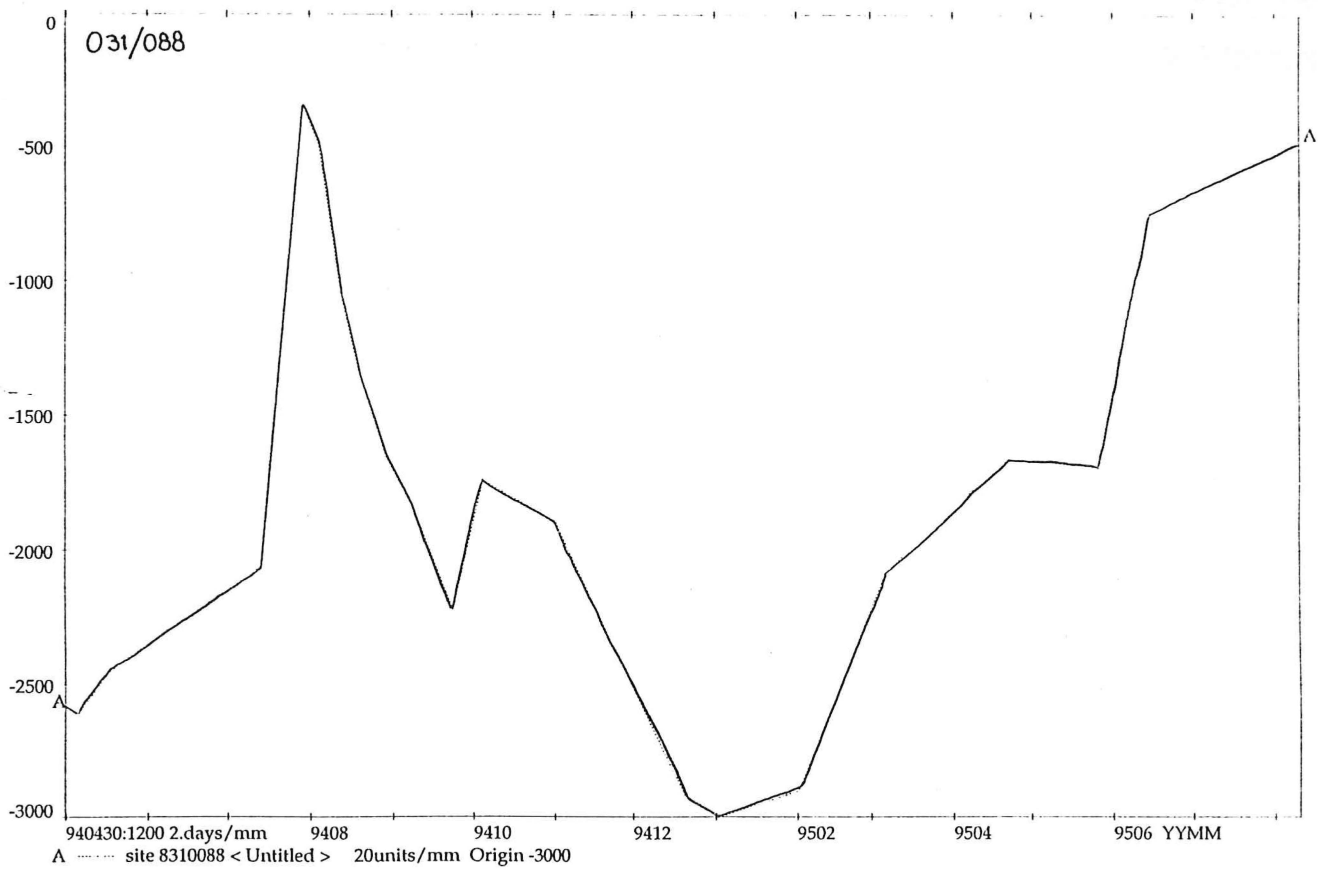
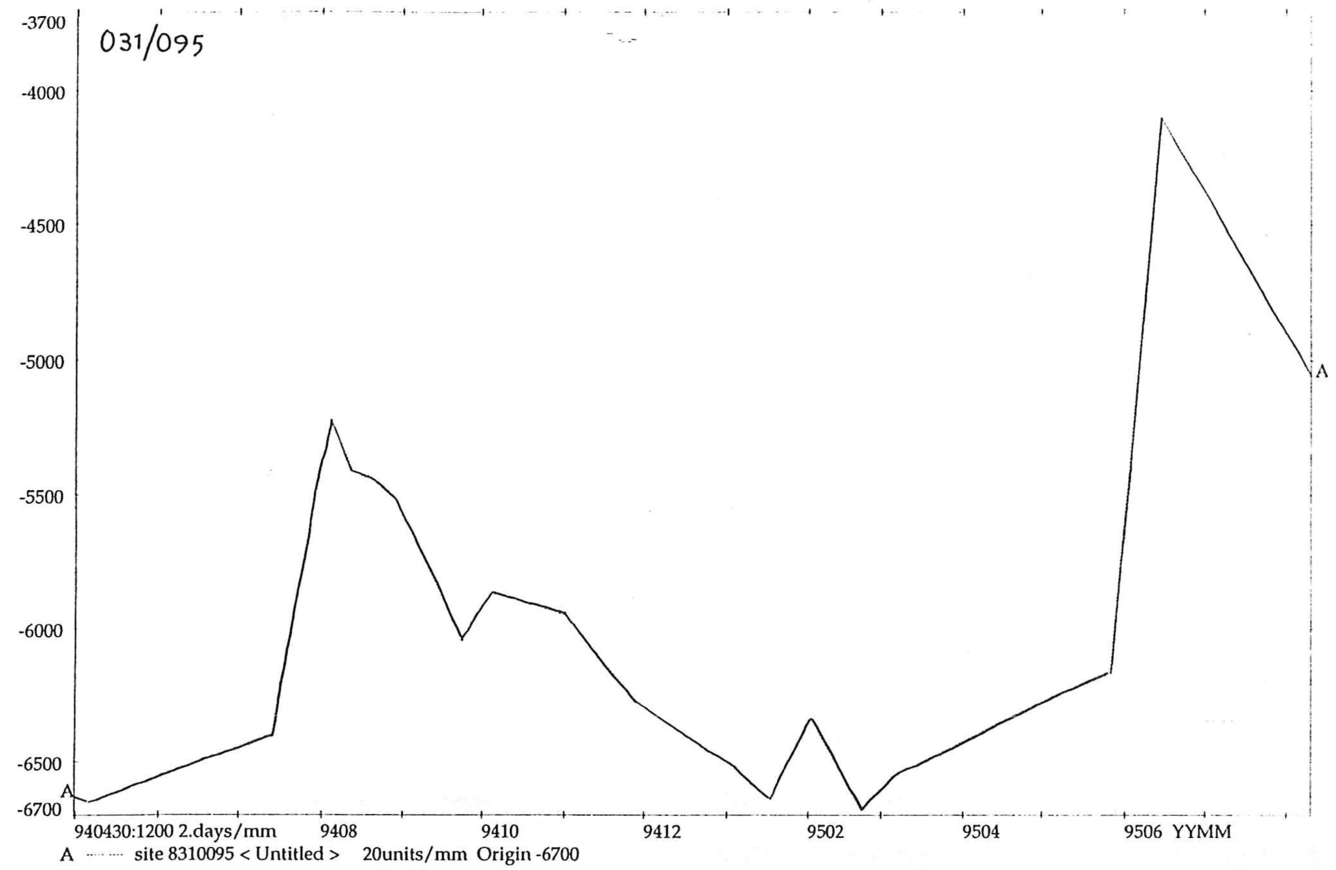
9408
9410
9412
9502
9504
9506 YYMM
A site 8310015 < Untitled > 5units/mm Origin -700


031/088
0
-500
-1000
-1500
-2000
-2500
-3000
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310088 < Untitled > 20units/mm Origin -3000


031/095
-3700
-4000
-4500
-5000
-5500
-6000
-6500
-6700
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
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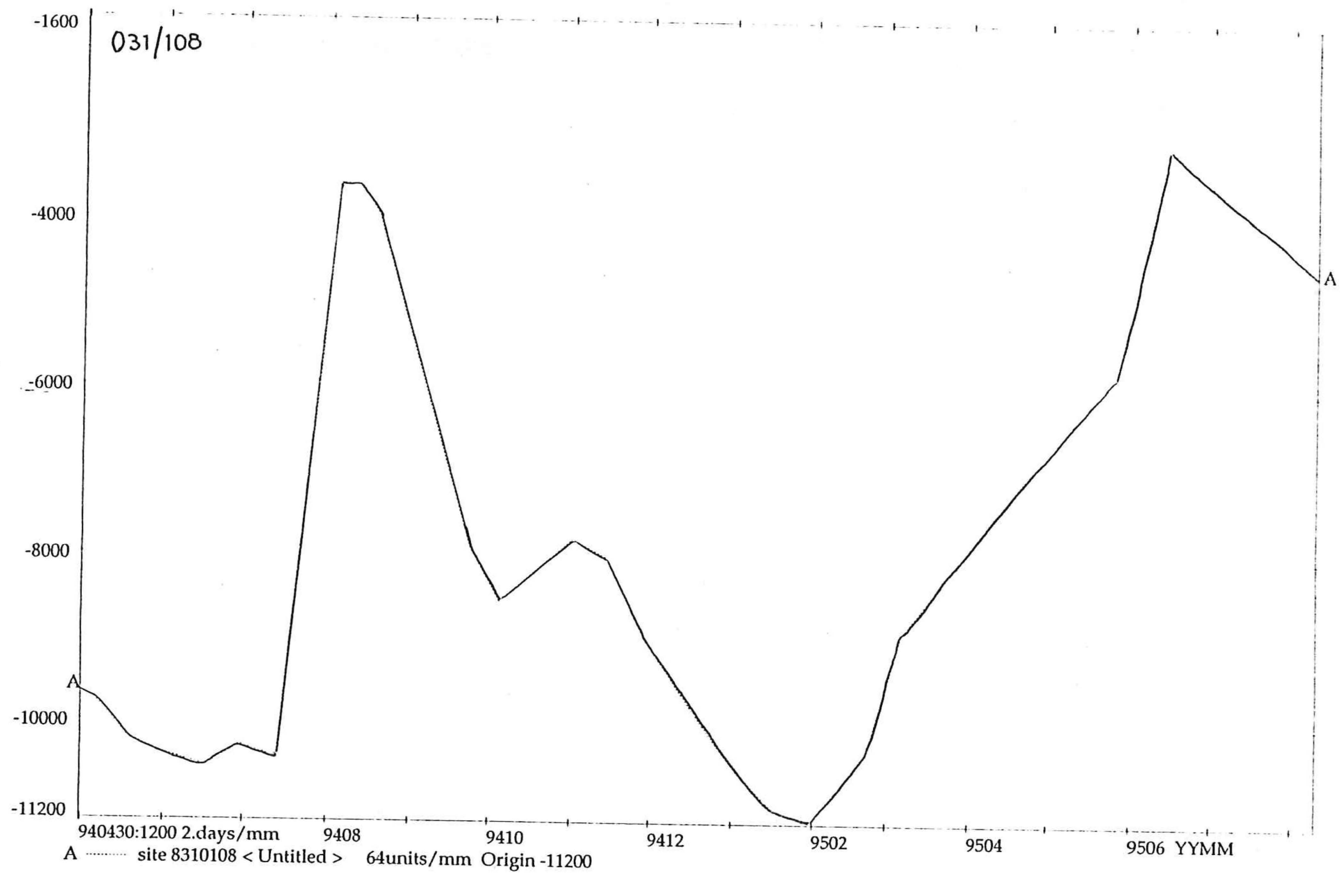
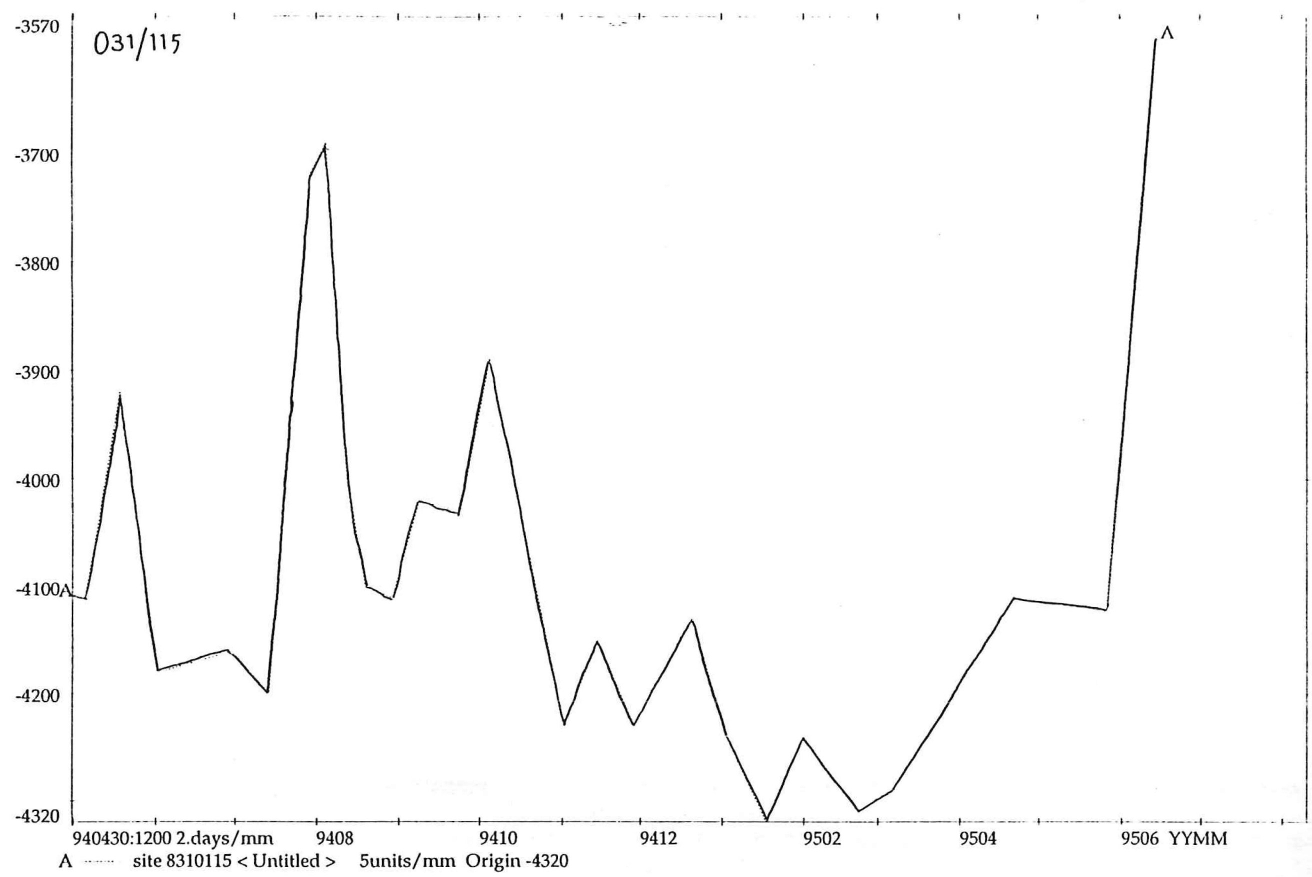
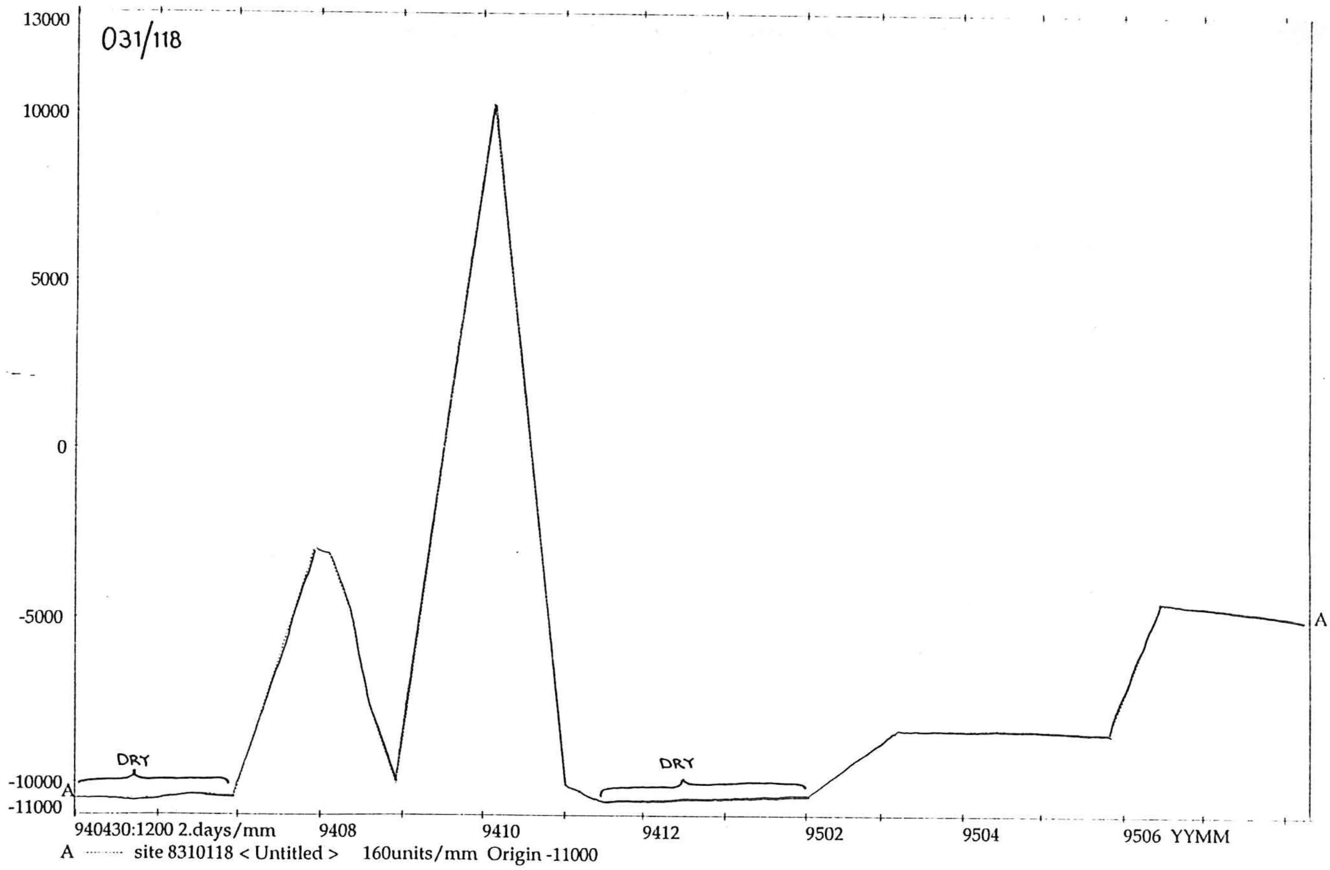
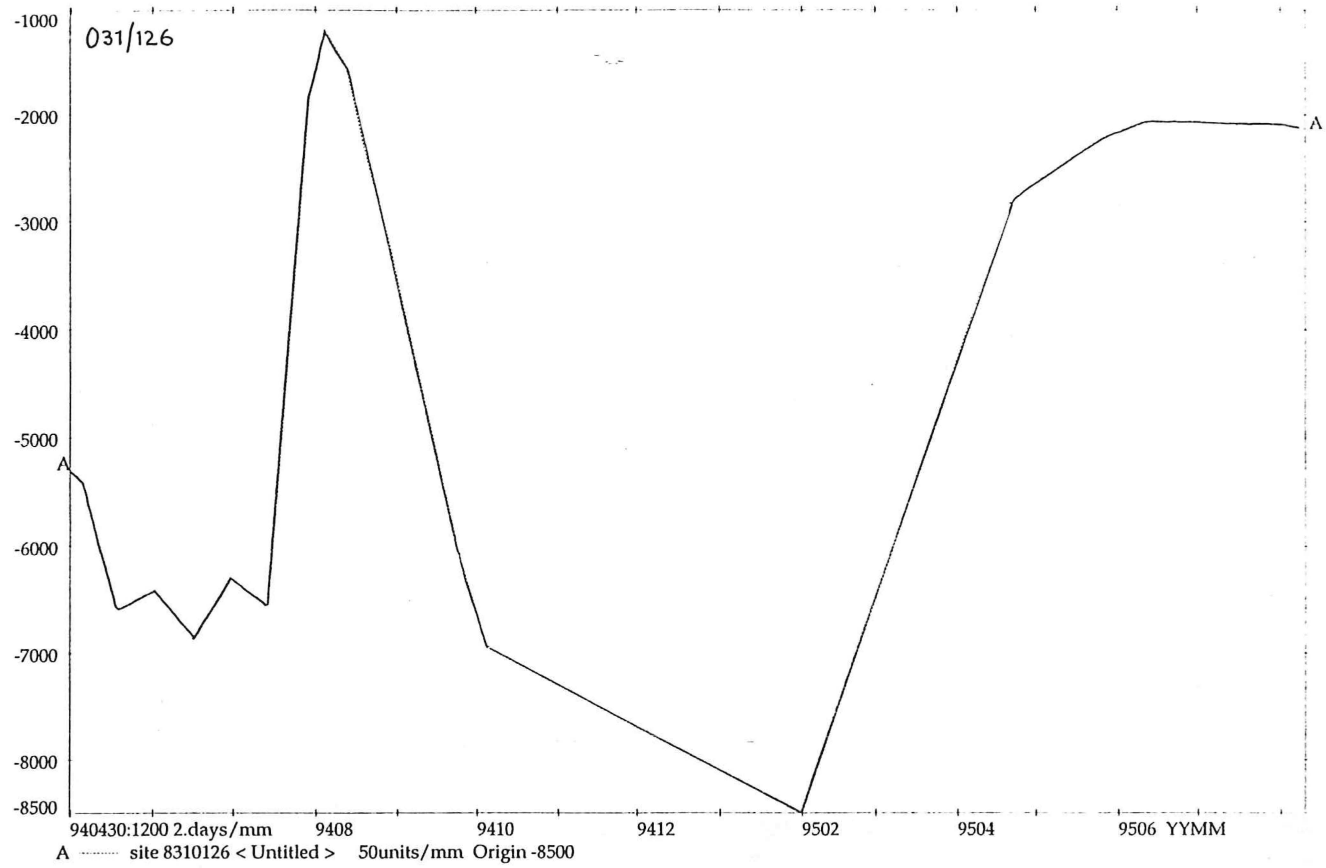

031/108
-1600
-4000
-6000
-8000
-10000
-11200
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310108 < Untitled > 64units/mm Origin -11200

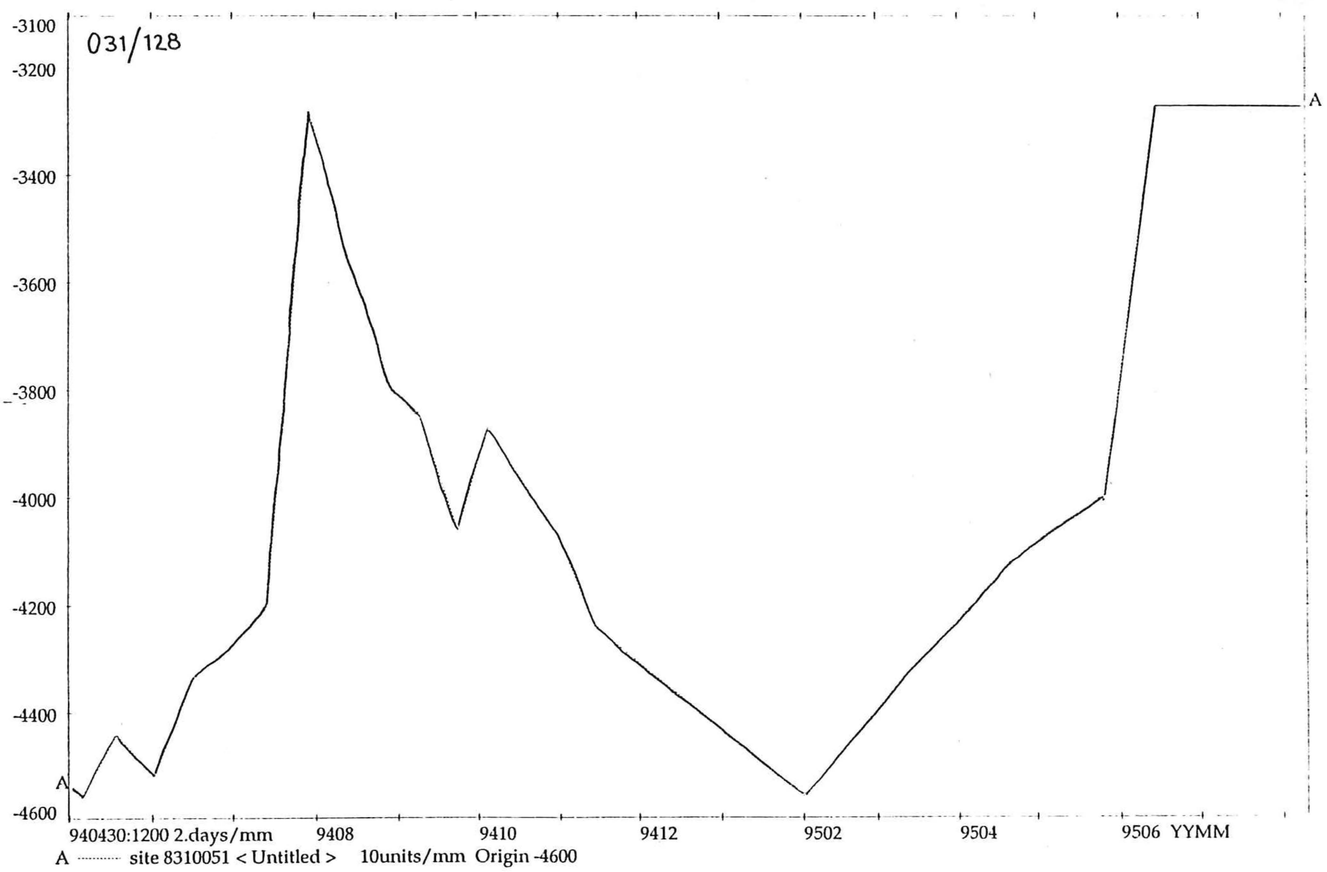


031/115
-3570
-3700
-3800
-3900
-4000
-4100
-4200
-4320
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310115 < Untitled > 5units/mm Origin -4320



031/118
13000
10000
5000
0
-5000
-10000
-11000
DRY
DRY
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310118 < Untitled > 160units/mm Origin -11000


031/126
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-8500
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A ········ site 8310126 < Untitled > 50units/mm Origin -8500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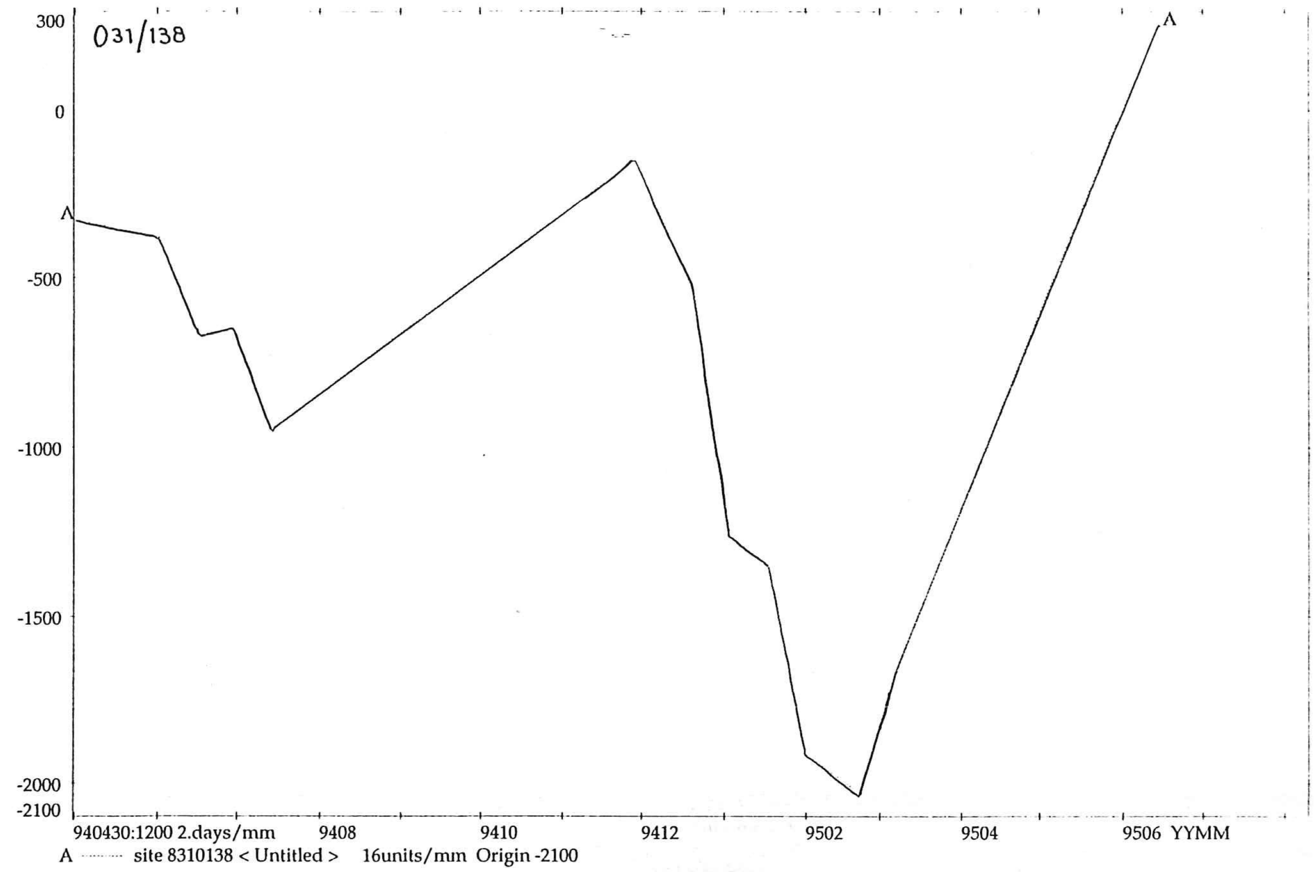
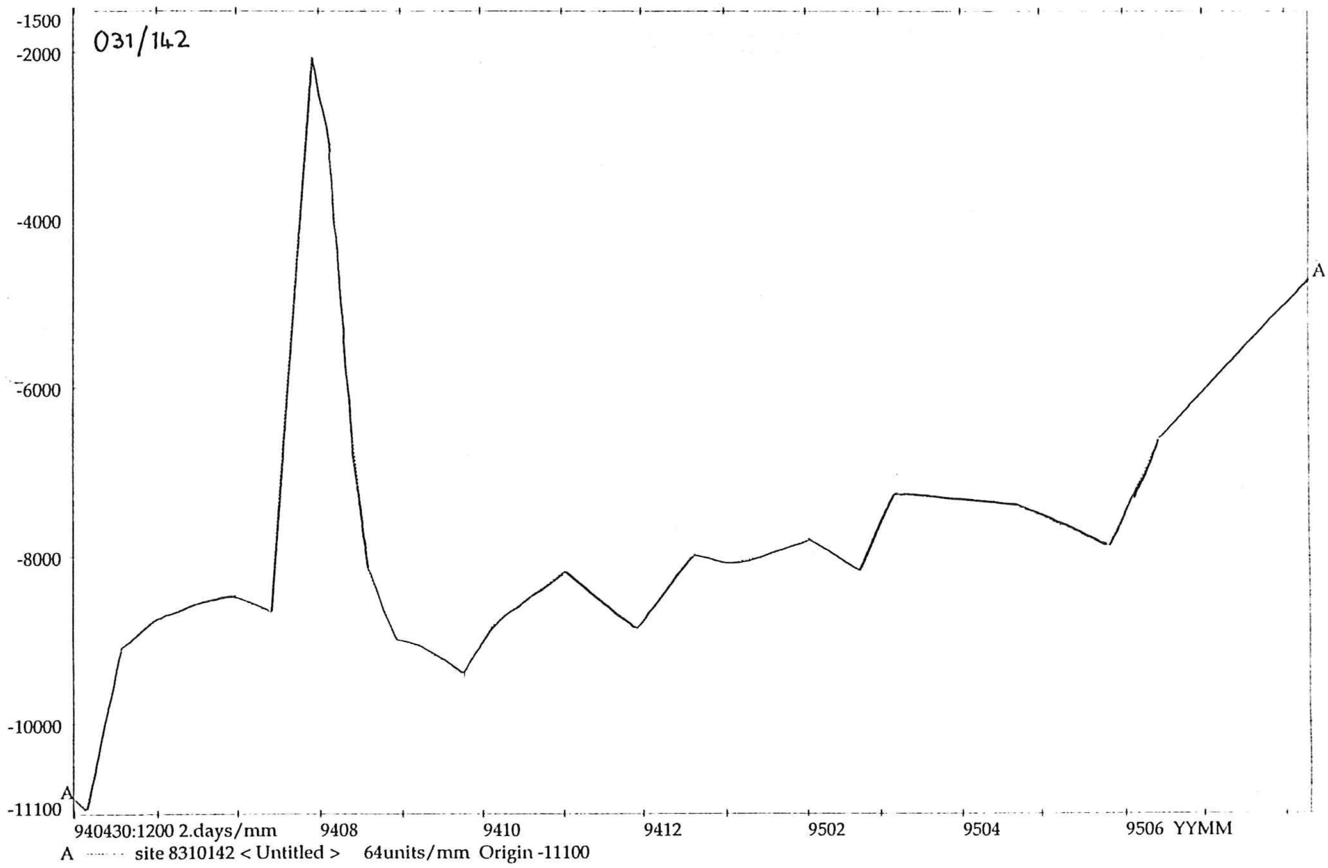
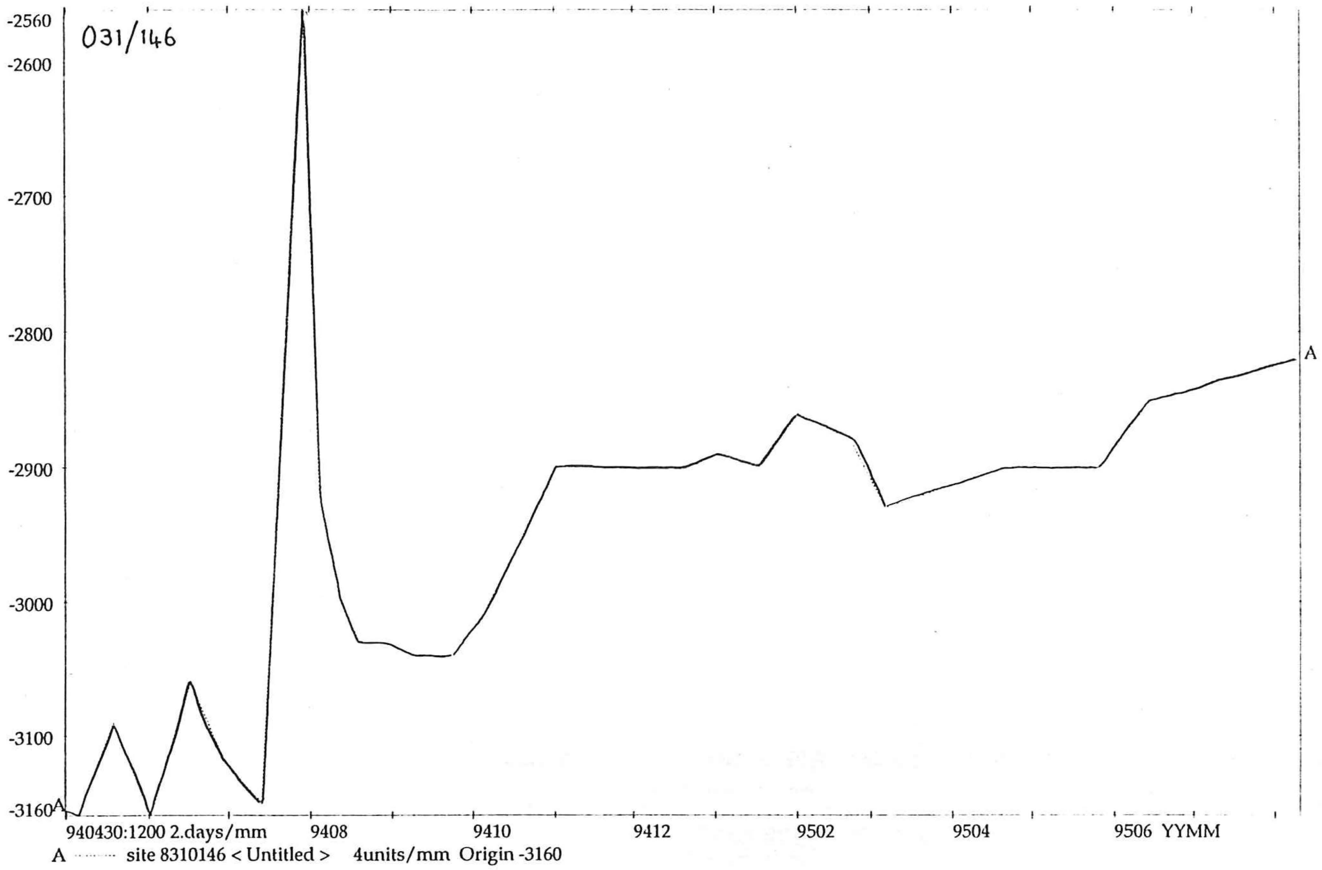
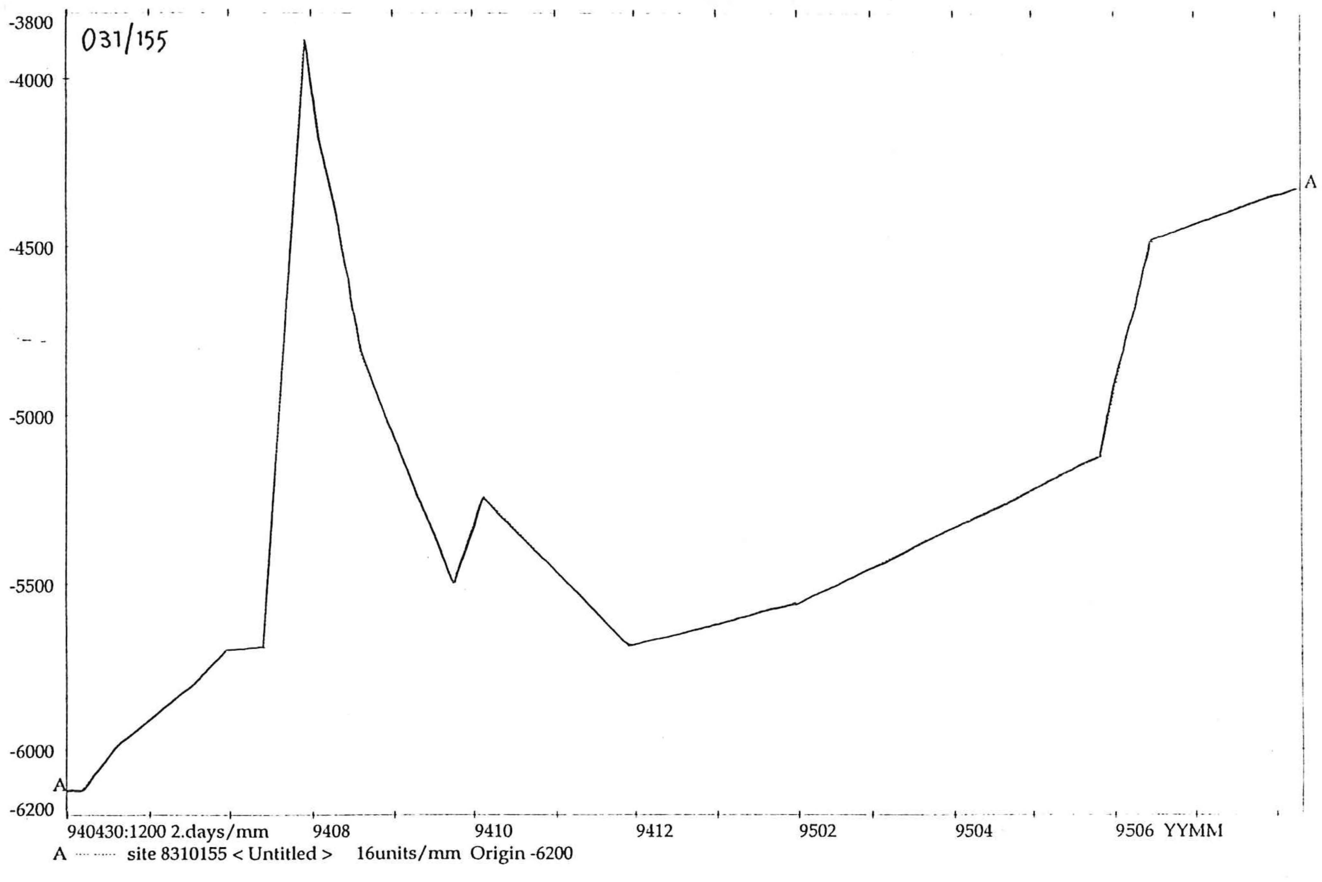
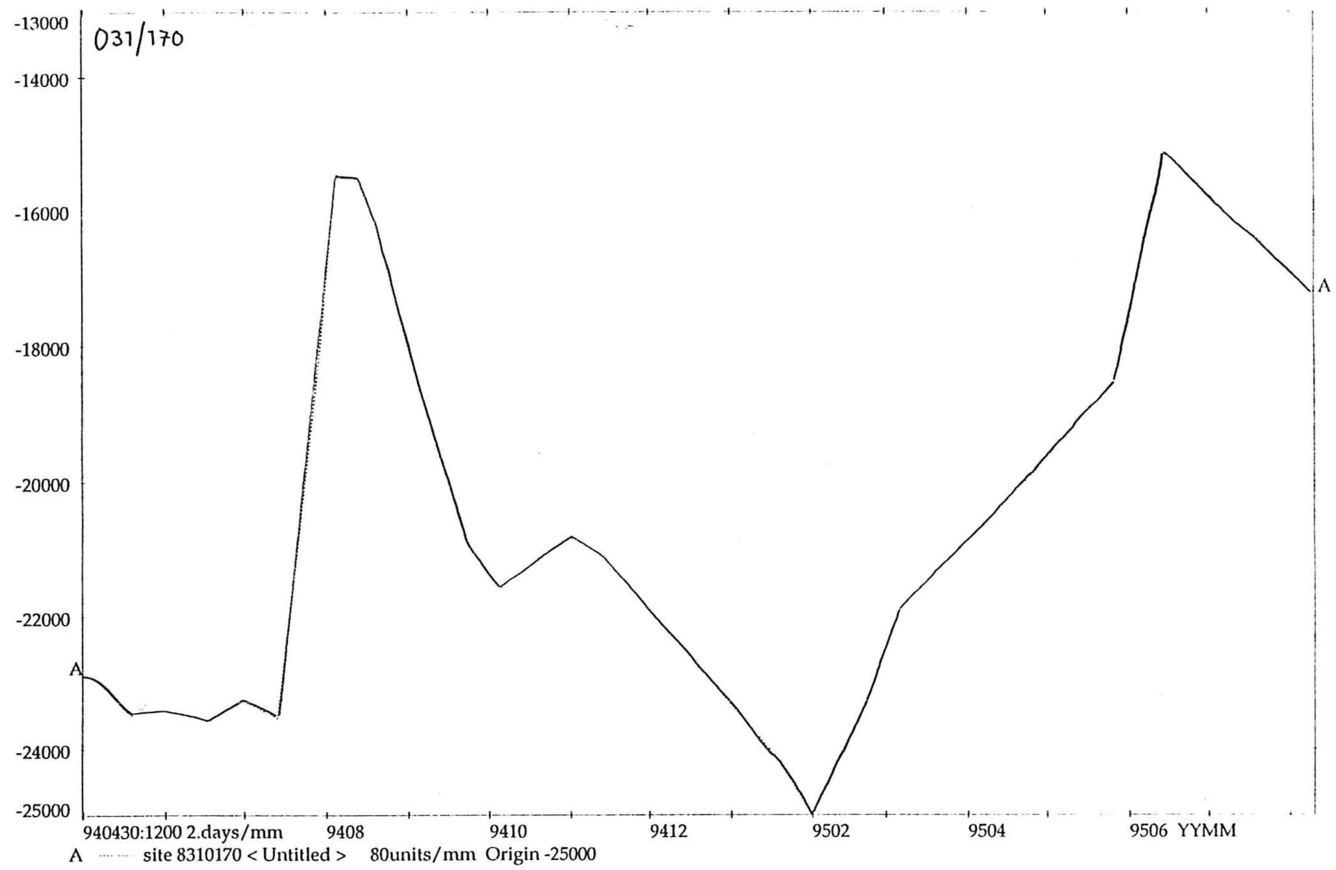
-3100
-3200
-3400
-3600
-3800
-4000
-4200
-4400
-4600
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A ········ site 8310051 < Untitled > 10units/mm Origin -4600

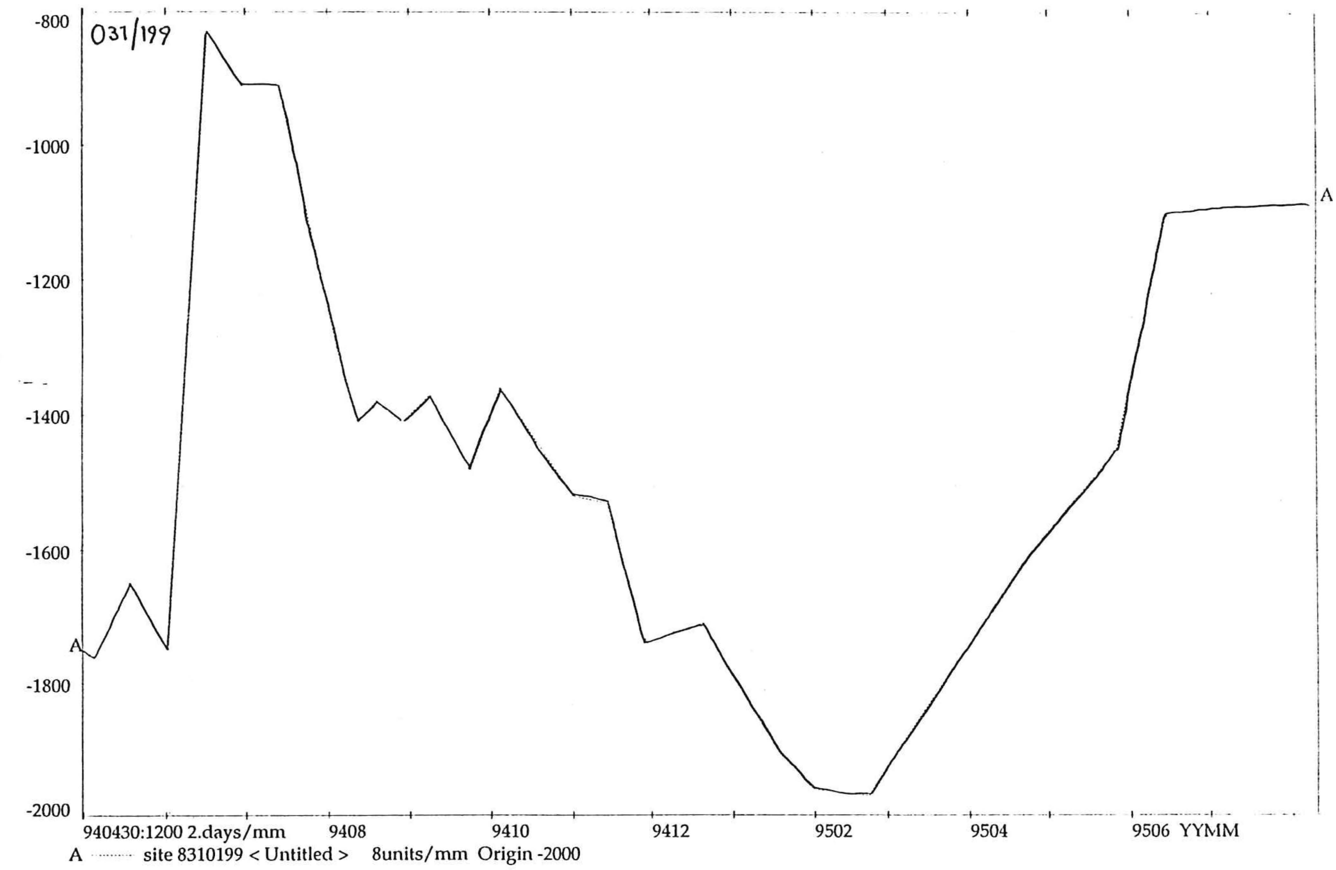

300
0
-500
-1000
-1500
-2000
-2100
031/138
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310138 < Untitled > 16units/mm Origin -2100

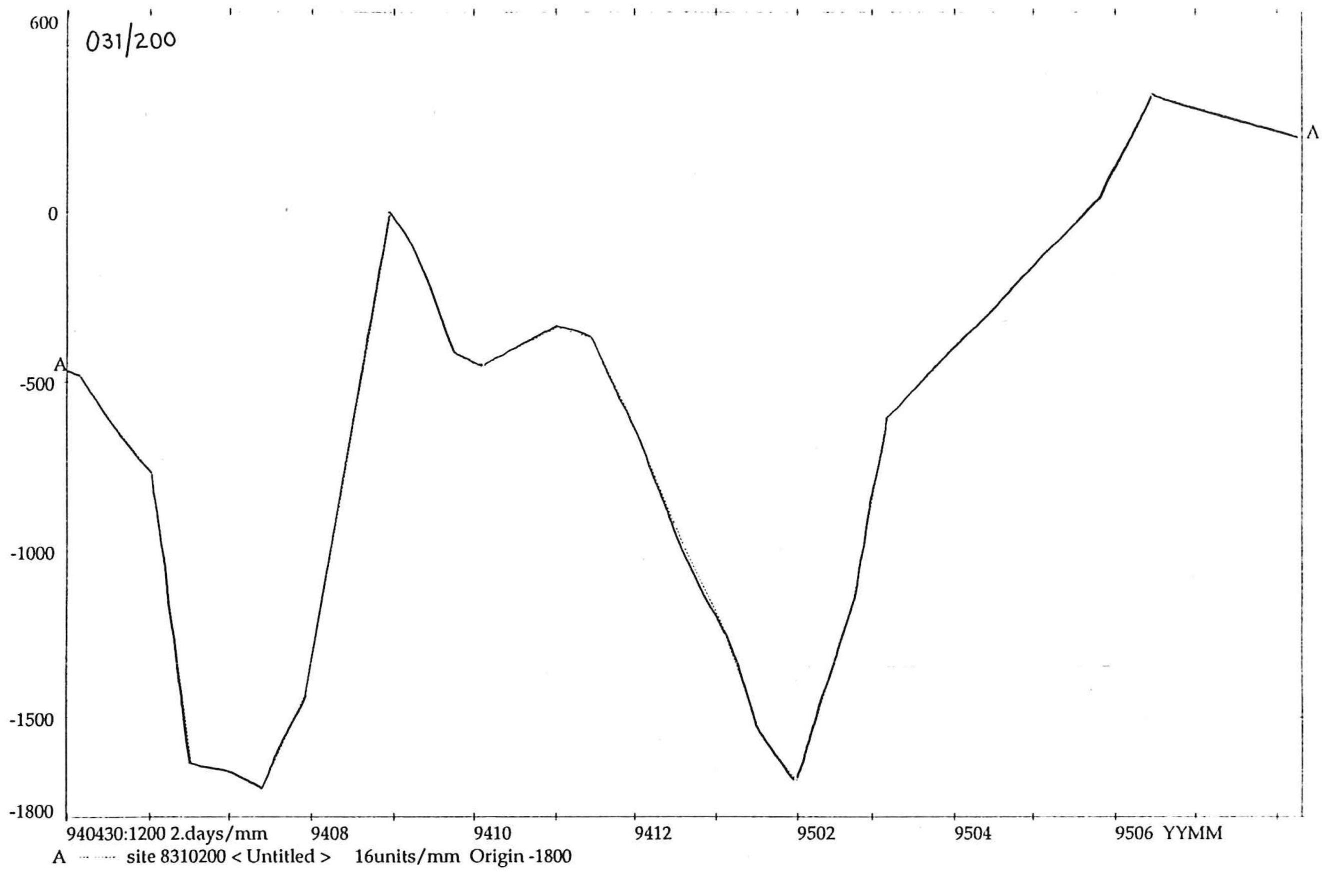

-1500
-2000
-4000
-6000
-8000
-10000
-11100
031/142
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310142 < Untitled > 64units/mm Origin -11100

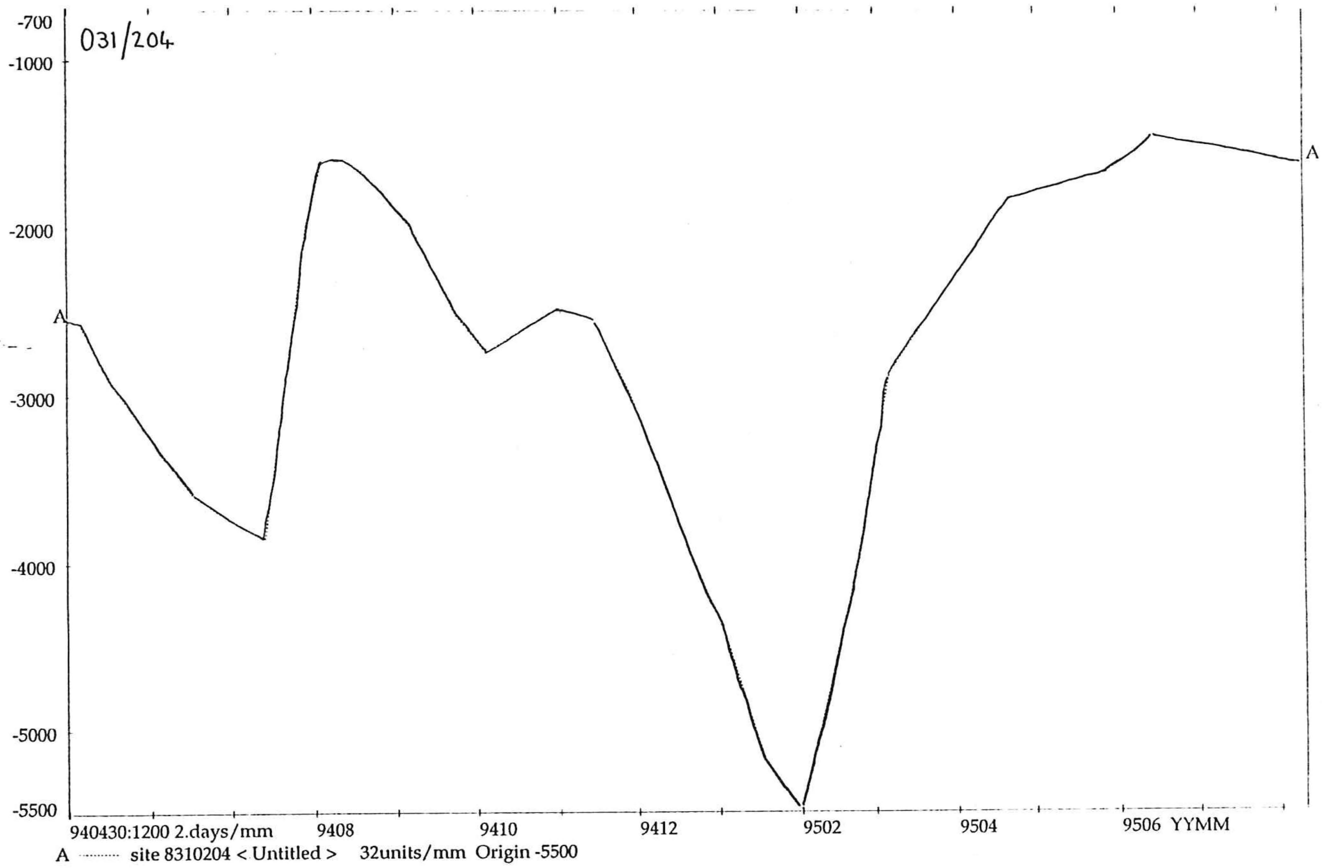

031/146
-2560
-2600
-2700
-2800
-2900
-3000
-3100
-3160
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310146 < Untitled > 4units/mm Origin -3160

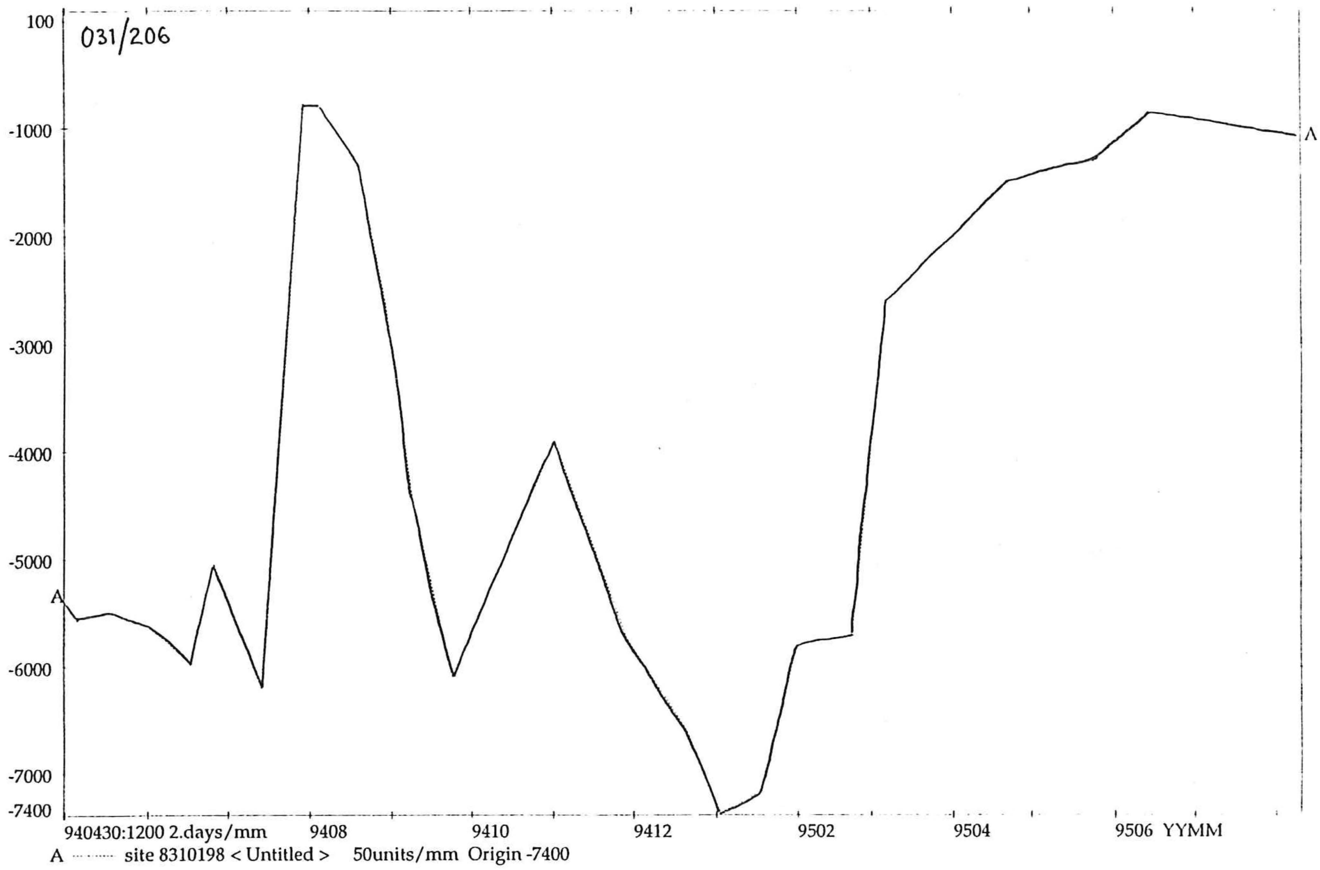

031/155
-3800
-4000
-4500
-5000
-5500
-6000
-6200
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310155 < Untitled > 16units/mm Origin -6200


031/170
-13000
-14000
-16000
-18000
-20000
-22000
-24000
-25000
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310170 < Untitled > 80units/mm Origin -25000


031/199
-800
-1000
-1200
-1400
-1600
-1800
-2000
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310199 < Untitled > 8units/mm Origin -2000

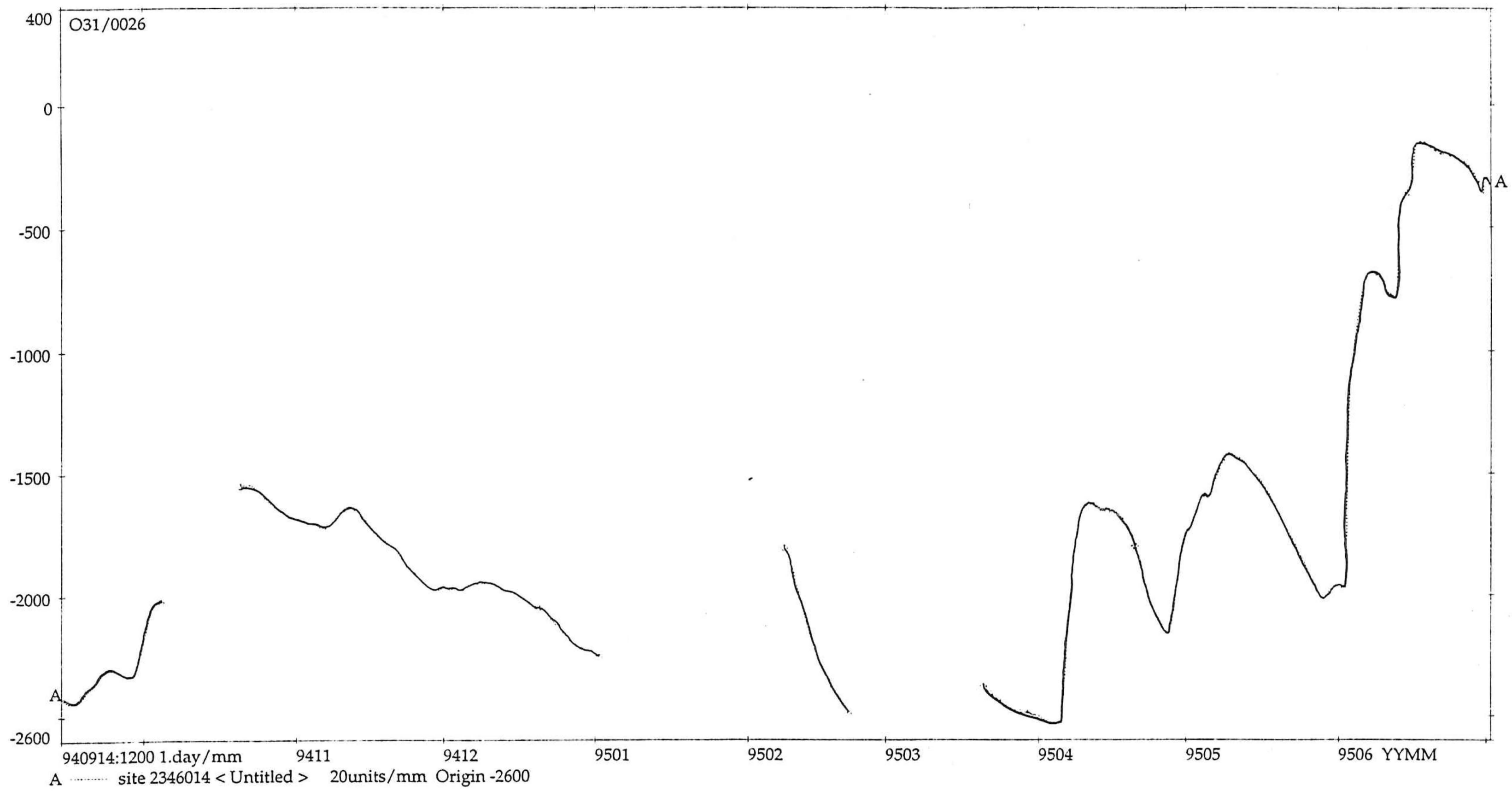

031/200
600
0
-500
-1000
-1500
-1800
A
A
940430:1200 2.days/mm 9408 9410 9412 9502 9504 9506 YYMM
A site 8310200 < Untitled > 16units/mm Origin -1800

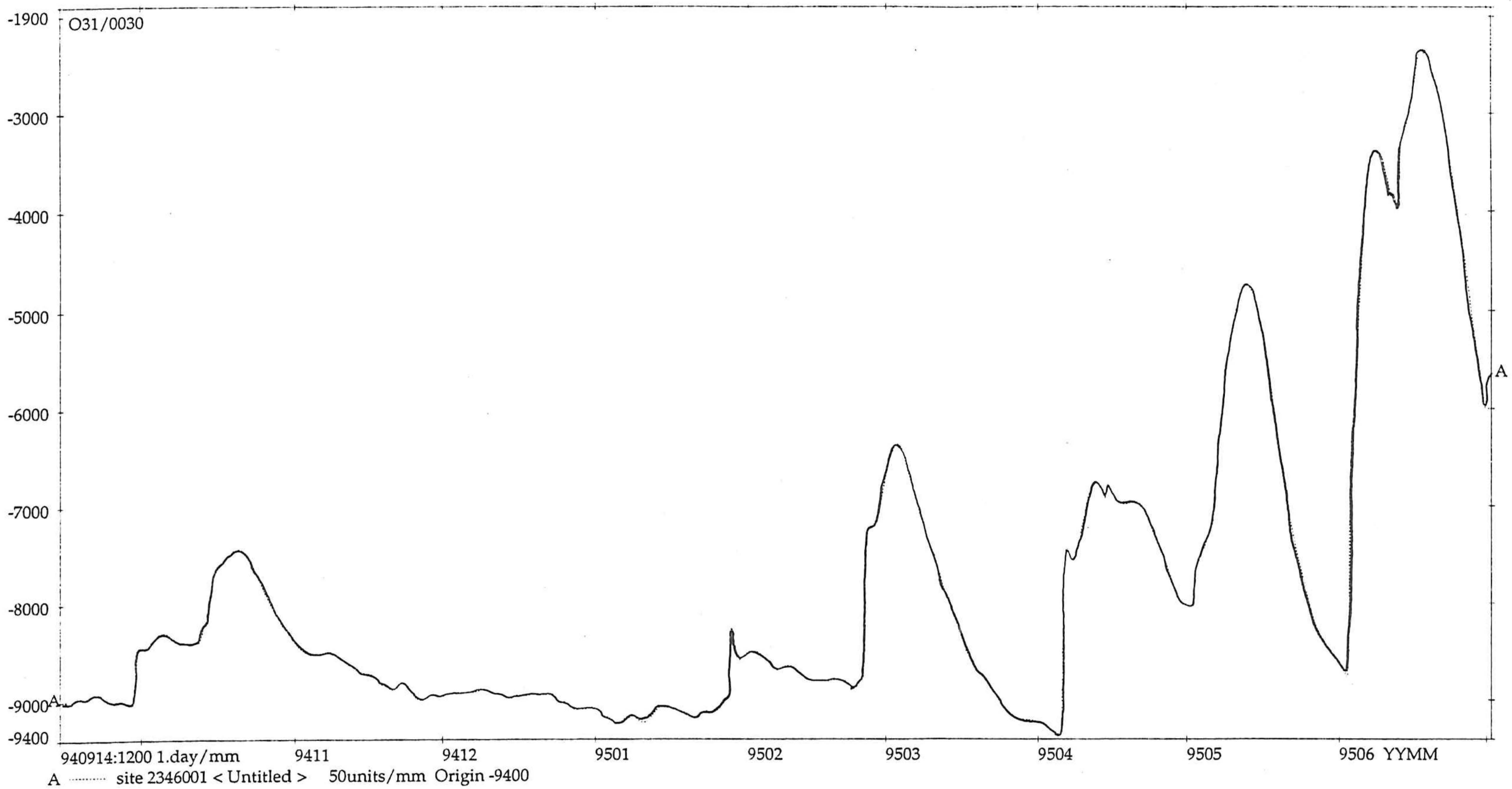

031/204
-700
-1000
-2000
-3000
-4000
-5000
-5500
A
A
940430:1200 2.days/mm 9408 9410 9412 9502 9504 9506 YYMM
A site 8310204 < Untitled > 32units/mm Origin -5500

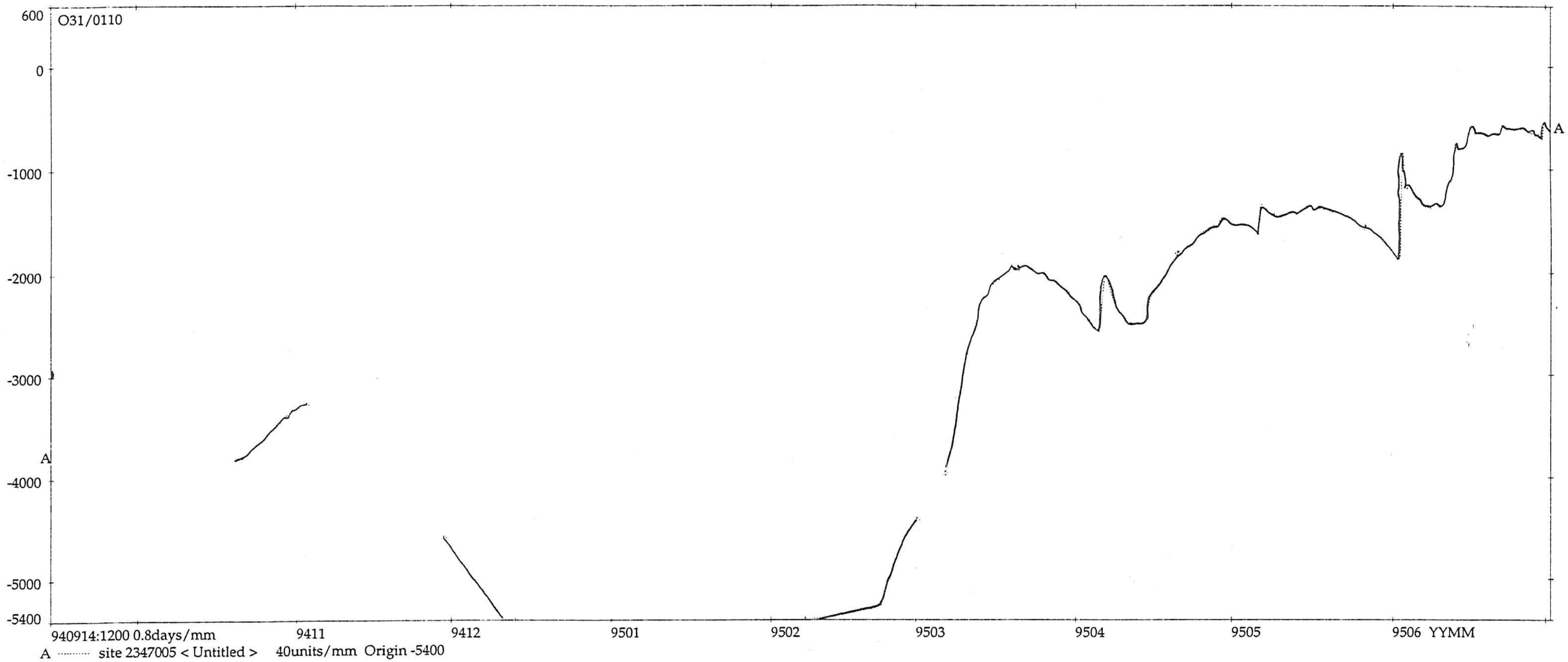


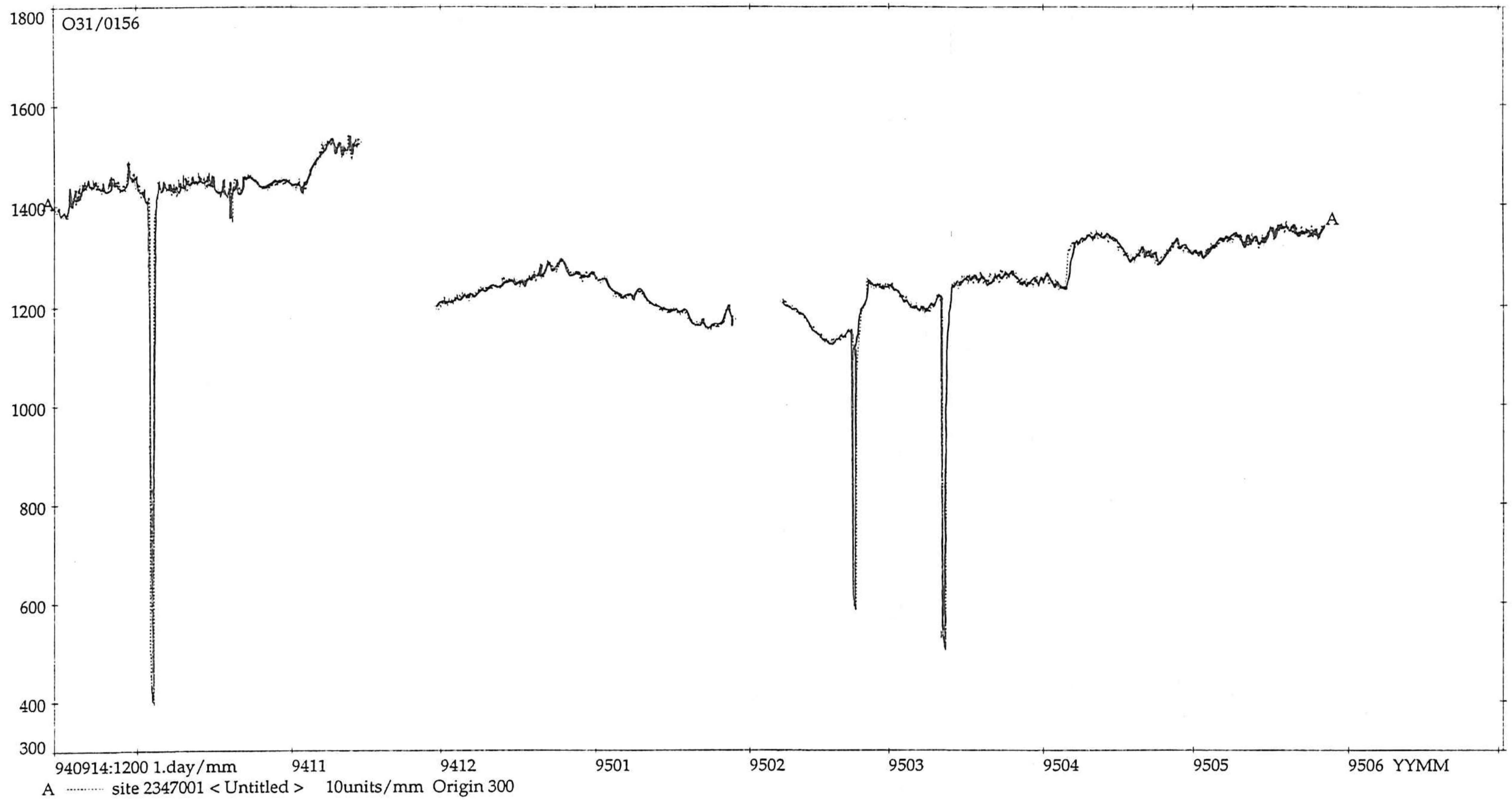
031/206
100
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-7400
A
A
940430:1200 2.days/mm
9408
9410
9412
9502
9504
9506 YYMM
A site 8310198 < Untitled > 50units/mm Origin -7400

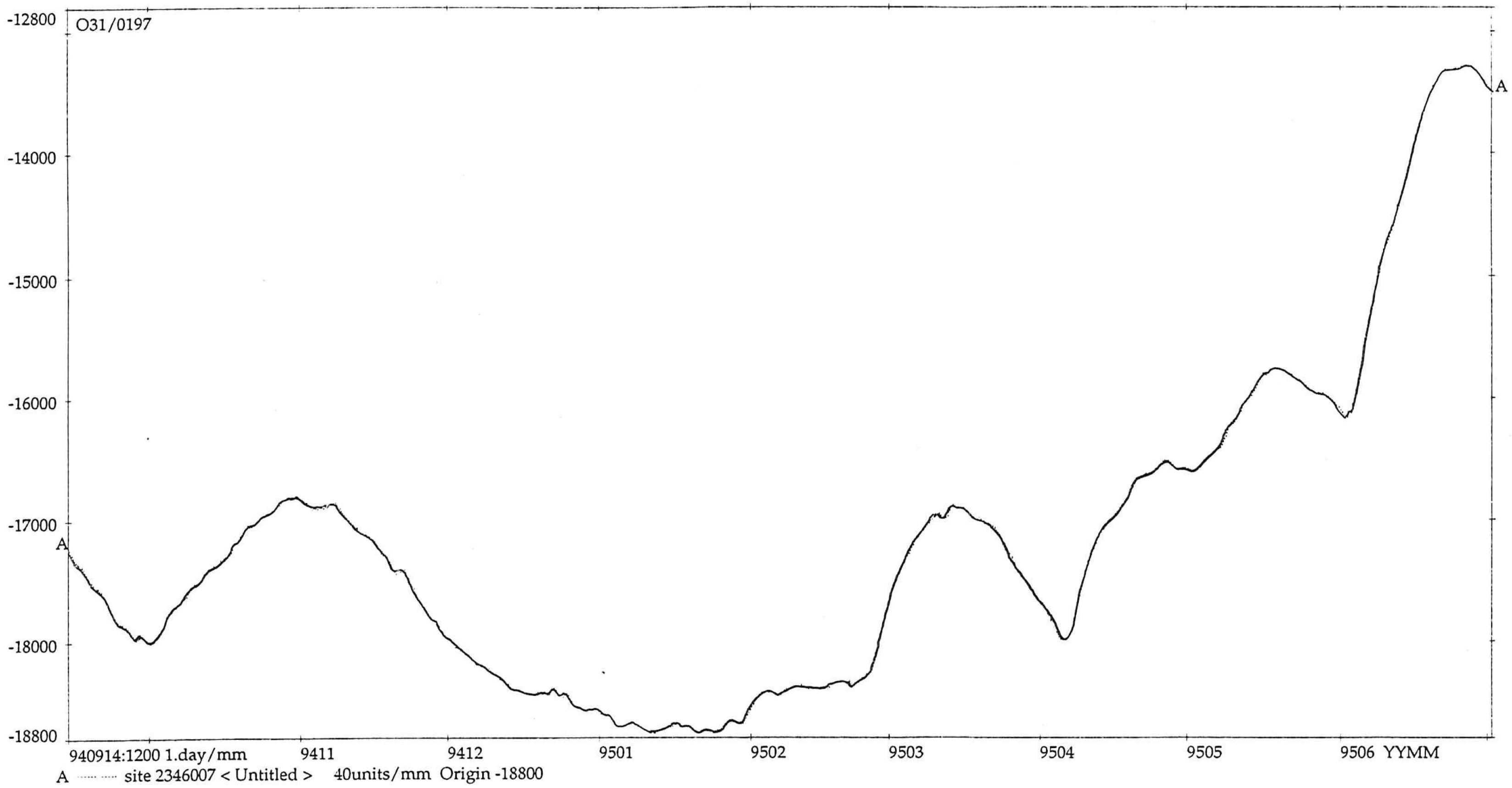
IX-II: Automatic Observation Wells


O31/0026
400
0
-500
-1000
-1500
-2000
-2600
A
A
940914:1200 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
A site 2346014 < Untitled > 20units/mm Origin -2600


O31/0030
-1900
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-9400
A
A
940914:1200 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
A ········ site 2346001 < Untitled > 50units/mm Origin -9400


O31/0110
600
0
-1000
-2000
-3000
-4000
-5000
-5400
A
A
940914:1200 0.8days/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
A ········· site 2347005 < Untitled > 40units/mm Origin -5400


O31/0156
1800
1600
1400
1200
1000
800
600
400
300
A
A
940914:1200 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
A ·········· site 2347001 < Untitled > 10units/mm Origin 300



O31/0197
-12800
-14000
-15000
-16000
-17000
-18000
-18800
A
A
940914:1200 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
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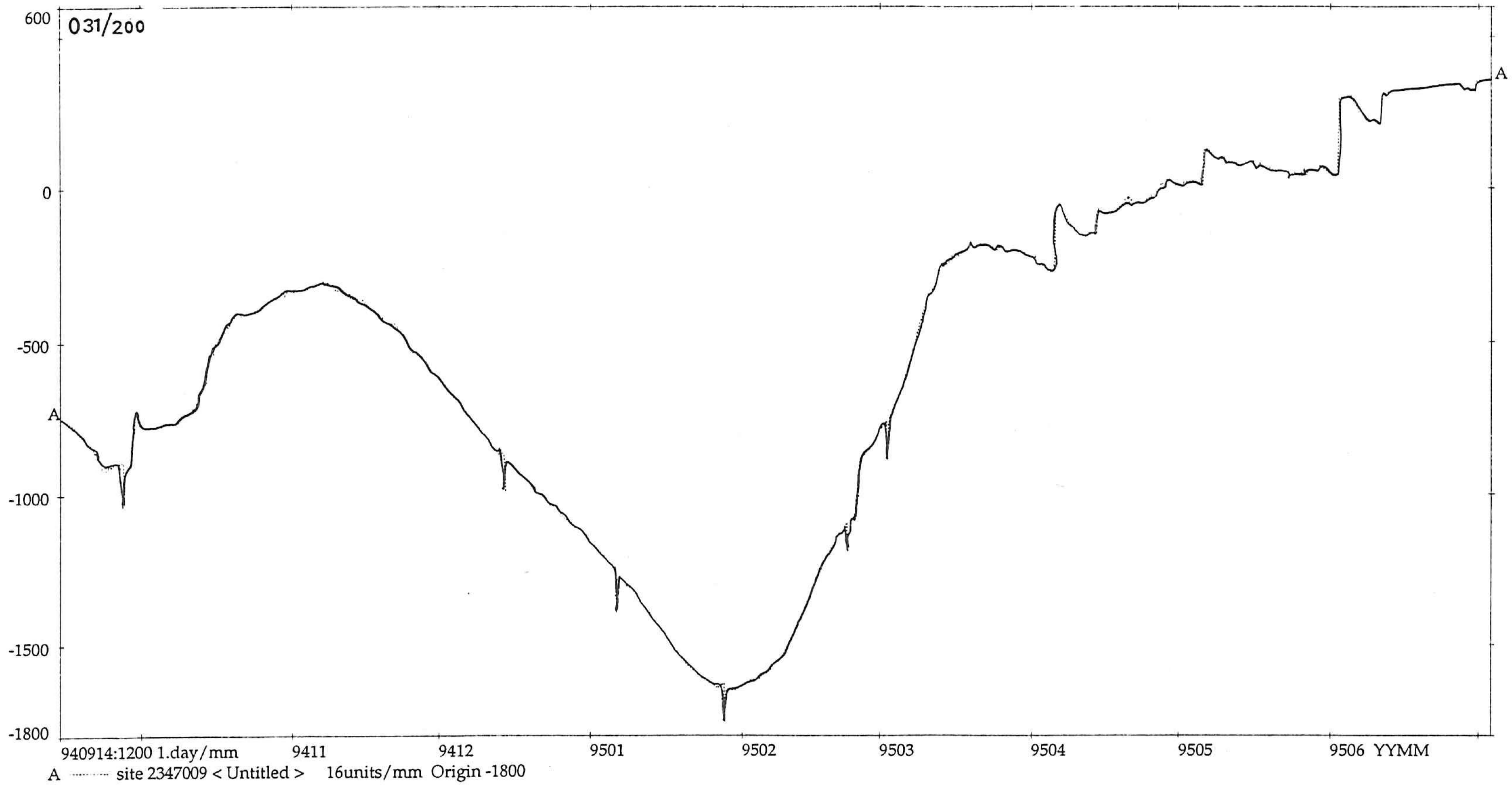
031/200
600
0
-500
-1000
-1500
-1800
A
A
940914:1200 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
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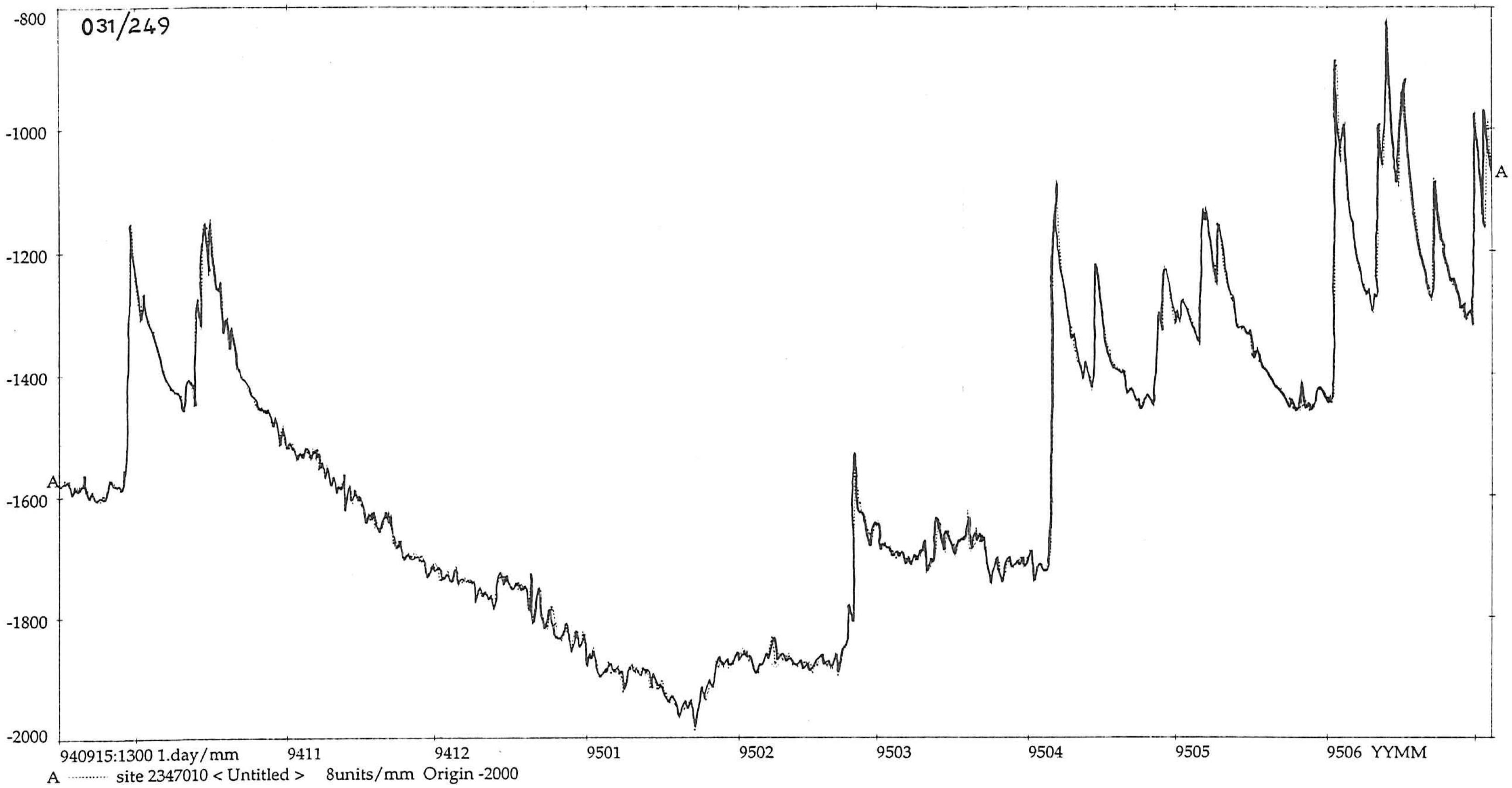
031/249
-800
-1000
-1200
-1400
-1600
-1800
-2000
A
A
940915:1300 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506 YYMM
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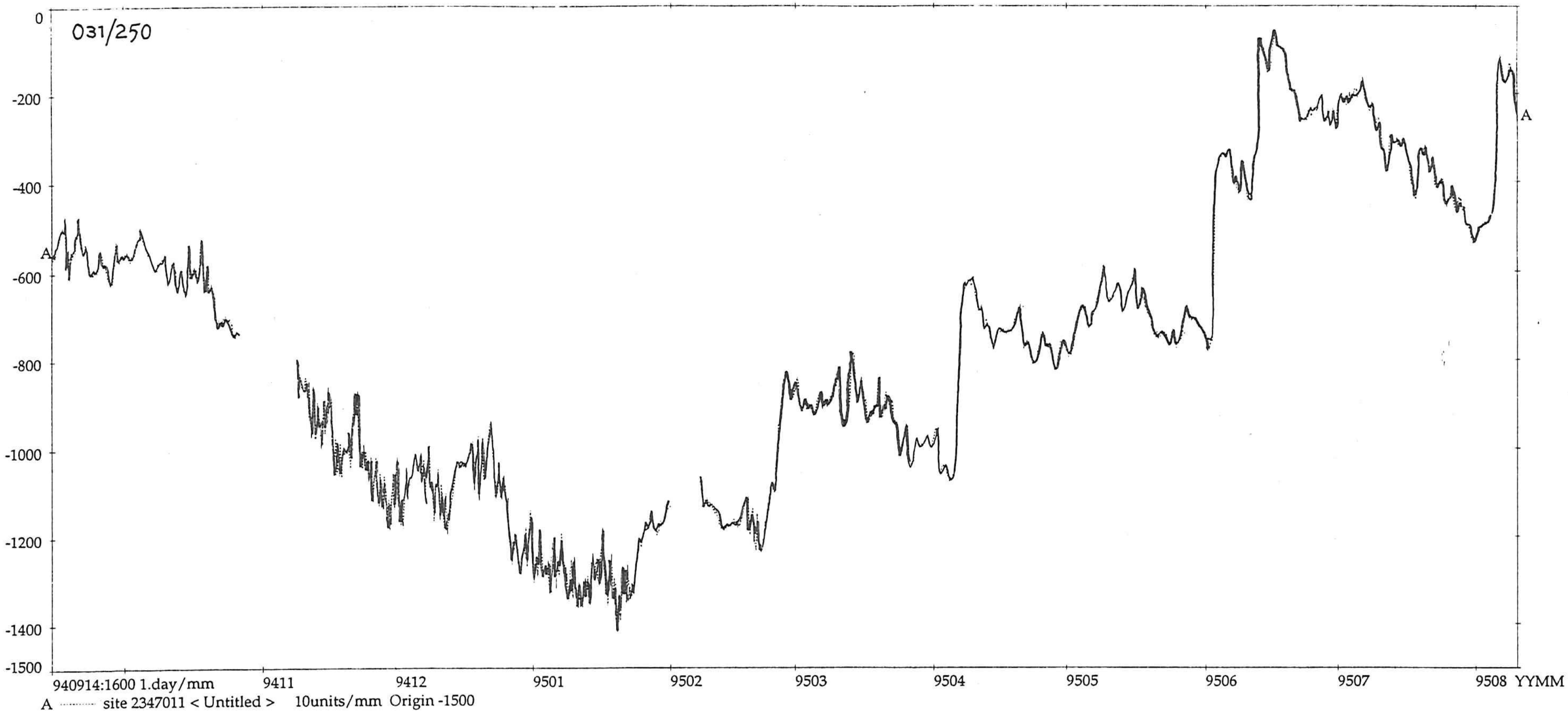

031/250
0
-200
-400
-600
-800
-1000
-1200
-1400
-1500
A
A
940914:1600 1.day/mm
9411
9412
9501
9502
9503
9504
9505
9506
9507
9508 YYMM
A site 2347011 < Untitled > 10units/mm Origin -1500

APPENDIX X: Water Chemistry.

X-I: SAMPLE SITES

Sample Site	CRC Site ID	Name/Well #	Grid Ref. O31:	Location	Owner
1	CRC:303333	Kowhai River	587-707	opposite end of Postmans Road.	
2	CRC:303329	Waimangarara River	635-761	above KDC infiltration gallery.	
3	CRC:303328	Luke Creek	623-741	above Topline Road.	
4	CRC:303330	O31/0121	659-721	Athelney Road	P. Hockey
5	CRC:303331	O31/0156	657-684	Hawthorne Road	CRC
6	CRC:303342	O31/0200	640-709	Mt. Fyffe Road	KDC
7	CRC:303340	O31/0197	602-679	Inland Road	Stokes
8	CRC:303339	O31/0259	608-651	S. H. 1	Rasmussen
9	CRC:303337	O31/0107	623-702	Schoolhouse Road	Lilley
10	CRC:303332	O31/0096	606-651	S. H. 1	Mackenzie
11	CRC:303344	O31/0056	649-696	Mill Road	Peoples
12	CRC:303343	O31/0264	653-680	Rorrisons Road	Harnett
13	CRC:303345	O31/0255	659-625	Harnetts Road	Murdock
14	CRC:303341	O31/0026	613-690	Kowhai Ford Road	Hutcheson
15	CRC:303338	O31/0219	628-661	S. H. 1	Fearnley
16	CRC:303336	O31/0238	699-746	Beach Road	Nelson
17	CRC:303335	O31/0127	694-765	Beach Road	Dovey
18	CRC:303334	O31/0110	639-722	Postmans Road	Mackle

X-II: DETERMINANTS AND METHODS OF ANALYSIS

Determinant	Abreviation	Method of Analysis	Units
Hydrogen Ion Activity	pH	Hach One pH/ISE meter	pH
Conductivity	Cond	Radiometer CDM2e meter	mS/m @ 25'c
Nitrate (& Nitrite) Nitrogen	NNN-1	Cadmium reduction or UV method A220nm - 2(A275nm) or Ion chromatography	g/m^3
Ammoniacal Nitrogen	NH3-1	Idophenol blue colorimetry	g/m^3
Bicarbonate Alkalinity	HCO3-1	Titration to pH 4.5	g/m^3
Chloride	Cl-1	Mercuric Nitrate titration	g/m^3
Sulphate	SO4-1	Barium perchlorate titration or Ion chromatography	g/m^3
Calcium Dissolved	CAD-1	AAS direct aspiration Air - Ac	g/m^3
Magnesium Dissolved	MGD-1	AAS direct aspiration Air - Ac	g/m^3
Sodium Dissolved	NAD-1	Atomic emmision Air - Ac flame	g/m^3
Total Hardness	THD-1	Calculated	g/m^3
Potassium Dissolved	KD-1	Atomic emmision Air - Ac flame	g/m^3
Faecal Coliforms	FC-1	MF 100ml MFC agar	n/100ml
Total Coliforms	COL-1	MF 100ml	n/100ml
Total Dissolved Solids	TDS	Calculated	g/m^3
Sodium Absorption Ratio	SAR	Calculated	
Free Carbon Dioxide	CO2	Calculated	g/m^3
Reactive Silica	SiO2	Heteropoly blue, auto	g/m^3
Manganese	Mn	Flame AAS	g/m^3
Iron	Fe	Flame AAS	g/m^3

X-III: RESULTS

Round 1: Sampled October, 1994.

Sample Site	1	2	3	4	5	6	7	8	9
pH	8.1	7.9	7.9	6.5	7.3	6.6	7.3	7.4	7.1
COND.	14.7	11.4	10.5	12.9	31.8	12	27.4	28.1	21.9
NNN-1	0.027	0.015	<.010	0.5	0.05	0.63	1.2	0.3	0.8
NH3-1	<0.005	<0.005	0.01	<0.005	0.34	0.035	<0.005	<0.005	<0.005
HCO3-1	68	52	49	59	200	56	141	155	113
CL-1	2	2	3	5	5	5	6	8	4
SO4-1	16	12	7	8	<5	5	14	6	13
CAD-2	24	19	16	13	30	11	43	36	34
MGD-1	2.2	1.6	1.9	3.9	9.3	2.9	4.7	6.7	3.9
NAD-1	3.4	3.3	3.4	7.5	28	5.8	7.6	13	6.1
THD-1	69	54	48	49	71	39	36	48	54
KD-1	1.3	0.5	0.7	1.1	1.5	0.8	1.3	1.2	1.2
FC-2	1	28	27	<1	<1	<1	<1	<1	<1
COL-2	7	48	400	<1	<1	<1	5	<1	1
TDS	116.9	90.4	81	97.5	261.8	86.5	181.3	198.1	156.2
SAR	0.94	1.03	1.14	2.58	6.3	2.2	1.56	2.81	1.4

Sample Site	10	11	12	13	14	15	16	17	18
pH	6.9	7.8	6.8	6.4	6.8	7	6.4	7	3.4
COND.	27.5	31.6	58	17.4	23.7	19.8	20.2	16.3	12.8
NNN-1	3	1.9	0.45	1.4	0.071	0.3	1.4	0.024	2.2
NH3-1	<0.005	<0.005	0.338	0.01	<0.005	0.007	0.011	<0.005	0.041
HCO3-1	114	130	370	77	127	93	47	74	44
CL-1	12	14	8	10	5	6	27	2	6
SO4-1	19	21	<5	6	12	13	18	16	11
CAD-2	36	43	56	20	39	24	15	24	12
MGD-1	6.4	5.4	25	3.7	3.6	4.5	4.9	2	3.3
NAD-1	11	10	34	8.3	5.8	9.1	16	4.4	7.3
THD-1	54	38	111	65	42	78	58	68	44
KD-1	0.9	4	3.4	1	1.1	1.3	4.1	4	1
FC-2	<1	<1	15	<1	2	<1	3	<1	3
COL-2	<1	<1	1000	<1	4	1	26	<1	60
TDS	174.3	190.6	448.5	126	165.5	150.9	132	126.4	84.6
SAR	2.45	2.03	5.34	2.41	1.26	2.41	5.07	1.22	2.64

Round 2: Sampled February, 1995.

Sample Site	4	5	6	7	8	9	10
pH	6.4	7.3	6.8	7.5	7.3	7.1	6.9
COND.	14	32	12	27	28	22	27
NNN-1	0.73	0.32	0.8	0.84	0.39	0.54	2.5
NH3-1	<0.005	0.011	0.027	<0.005	<0.005	<0.005	<0.005
HCO3-1	64	210	57	140	160	120	120
CL-1	7	6	5	6	9	4	11
SO4-1	5.8	<0.4	5.2	13	7.1	11	17
CAD-2	14	37	13	46	41	37	40
MGD-1	4	8	2.9	6	7	4	6
NAD-1	8	27	6.3	7.4	14	6.3	11
THD-1	51	110	44	140	120	99	140
KD-1	0.94	0.93	0.8	1.2	1.2	1.1	1.4
FC-2	<1	<1	<1	0	0	0	0
COL-2	<1	<1	<1	<1	1	<1	<1
TDS							
SAR	2.7	5.69	2.23	1.45	2.86	1.39	2.29
CO2	39	18	16	7	12	17	24
SiO2	19	33	15	12	22	12	13
Mn	<0.02	0.48	0.03	<0.02	0.26	<0.02	<0.02
Fe	0.1	1.4	<0.1	<0.1	0.1	0.3	<0.1

Sample Site	11	13	14	15	16	17	18
pH	7.6	6.5	6.7	6.9	6.8	7	6.4
COND.	37	13	21	21	15	16	15
NNN-1	0.5	0.3	<0.1	0.85	0.6	<0.1	3
NH3-1	0.009	0.013	0.055	<0.005	0.015	0.028	0.011
HCO3-1	190	58	110	98	64	78	35
CL-1	13	5	3	9	6	2	10
SO4-1	16	9.9	12	13	11	15	16
CAD-2	67	14	37	27	14	23	13
MGD-1	1	2.9	4	4.6	3.8	2	3.6
NAD-1	11	7.2	5.5	9.6	10	4.3	8
THD-1	160	47	110	86	51	66	47
KD-1	4.2	0.92	1	1.3	3	0.93	2.8
FC-2	<1	0	0	0	<2	4	>200
COL-2	6	<1	44	<1	55	29	>400
TDS							
SAR	1.89	2.48	1.21	2.42	3.85	1.22	2.78
CO2	7	31	40	18	18	13	20
SiO2	14	13	12	13	13	8.4	14
Mn	<0.02	<0.02	0.02	<0.02	0.03	<0.02	<0.02
Fe	0.1	0.1	0.4	<0.1	0.8	<0.1	<0.1

X-IV: EXCERPTS FROM RELEVANT DRINKING WATER STANDARDS.

X-IV-I: DWSNZ 1984 (Department of Health, 1984)

Table 1. Microbiological and Biological Quality—*continued*

Organism	Unit	Guide-line value	Remarks	Document Reference: N.Z. Standards	Document Reference: WHO Guide-lines Vol. 1
B. Unpiped water supplies					
faecal coliforms	number/ 100 ml	nil		2.1.2.2	2.1.2.2
coliform organisms	number/ 100 ml	10	should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved an alternative source must be found if possible		

X-IV-II: DWSNZ 1995 (Ministry of Health, 1995)

Table 13.1 MAVs for micro-organisms of health significance

MICROORGANISM	MAV
Faecal coliform	Must not be detectable in 100 mL of sample
Viruses	No enteric viruses shall be detectable in 100L of sample.
Protozoa (pathogenic)	Not detectable in 100L sample.
Helminths (pathogenic)	Not detectable in 100L sample.
Algae	No toxic algae present in 10mL of sample

Table 13.2 MAVs for inorganic determinands of health significance

NAME	MAV	UNITS	REMARKS
Aluminium			NAD
Antimony	0.003	mg/L	
Arsenic	0.01	mg/L	For excess lifetime skin cancer risk of 6×10^{-4} P, for practical quantitative analysis
Asbestos			NAD
Barium	0.7	mg/L	
Beryllium			NAD
Boron	0.3	mg/L	
Bromate	0.025	mg/L	For excess lifetime cancer risk of 7×10^{-5}
Cadmium	0.003	mg/L	
Chlorate			NAD
Chlorine (free)	5	mg/L as Cl_2	ATO
Chlorite	0.3	mg/L as ClO_2	P, disinfection must never be compromised
Chromium	0.05	mg/L	P, limited information on health effects
Copper	2	mg/L	ATO
Cyanide (total)	0.08	mg/L	
Cyanogen chloride (as CN)	0.08	mg/L	
Dichloramine			NAD
Fluoride *	1.5	mg/L	
Iodine			NAD
Lead	0.01	mg/L	
Manganese	0.5	mg/L	ATO
Mercury (total)	0.002	mg/L	
Molybdenum	0.07	mg/L	
Monochloramine	3	mg/L	
Nickel	0.02	mg/L	
Nitrate	50	mg/L expressed as NO_3	The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed 1
Nitrite	3	mg/L expressed as NO_2	The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed 1. P, limited information on health effects
Potassium permanganate			NAD
Selenium	0.01	mg/L	
Silver			U
Sodium			NAD
Tin			U
Trichloramine			NAD
Uranium			NAD

* The fluoride content recommended for drinking-water by the Public Health Commission for oral health reasons is 0.7 - 1.0 mg/L.

Abbreviations:
P - Provisional MAV.
NAD - No adequate data to permit recommendation of a health-based MAV.
ATO - Concentrations of the substance at or below the health-based MAV may affect the appearance, taste or odour of the water.
U - Unnecessary to recommend health-based MAV because they are not hazardous to human health at concentrations normally found in drinking water.

Table 13.6 Guideline Values for aesthetic determinands

Determinand	Guideline Value	Units	Comments
Aggressiveness	LSI > 0		Corrosion
Aluminium	0.15	mg/L	Depositions, discoloration.
Ammonia	1.5	mg/L	Odour and taste
Calcium: see hardness		mg/L	
Chloride	250	mg/L	Taste, corrosion
Chlorophenols 2-chlorophenol 2,4-dichlorophenol 2,4,6-trichloro-phenol	 0.0001 0.0003 0.002	mg/L	 Taste Taste Taste
Colour	10	TCU	Appearance
Copper	1	mg/L	Staining of laundry and sanitary ware (health based provisional guideline value 2 mg/L)
Ethylbenzene	0.002	mg/L	For odour and taste (health based guideline value 0.3 mg/L)
Hardness (total) (Ca + Mg)	200	mg/L	High hardness causes scale deposition, scum formation; low hardness: possibly causes corrosion
Hydrogen sulphide	0.05	mg/L	Odour and taste
Iron	0.2	mg/L	Staining of laundry and sanitary ware
Magnesium (see hardness)		mg/L	
Manganese	0.05	mg/L	Staining of laundry and sanitary ware
Odour	should be acceptable to most consumers		
pH	6.5-8.5		Should be between 7.0 and 8.0. Low pH: corrosion; high pH: taste, soapy feel. Preferably pH<8 for effective disinfection with chlorine
Sodium	200	mg/L	Taste
Styrene	0.004	mg/L	For odour and taste (health based guideline value 0.03 mg/L)
Sulphate	250	mg/L	Taste, corrosion
Taste	should be acceptable to most consumers		
Temperature	should be acceptable to most consumers		
Toluene	0.024	mg/L	Odour and taste (health based guideline value 0.8 mg/L)
Total dissolved solids	1000	mg/L	Taste
Turbidity	2.5	NTU	Appearance, for effective terminal disinfection, median turbidity < 1 NTU, single sample < 5 NTU
Xylene	0.02	mg/L	Odour and taste (health based guideline value 0.6 mg/L)
Zinc	3	mg/L	Appearance, taste